D4.2 – Initial report on ontology implementation

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1. Executive Summary

This deliverable provides an initial report on the work done on ontology implementation during the first 24 months of ARIADNEplus, assessing it and planning the related activities for the second period, i.e. months 25-48. The activity happens primarily under T4.4, but related work also takes place under WP2 (Extending and Supporting the ARIADNE community), WP5 (Extending the ARIADNEplus data infrastructure), WP12 (data integration and interoperability), and WP14 (The ARIADNEplus knowledge management system), and these provide the focus of other deliverables either already submitted (D2.2 and D5.2) or due shortly (D12.2 and D14.1).

The overall objective of WP4 is to Integrate the datasets of the Archaeological Research Communities, and Task 4.4 is focussed on Implementing the ARIADNE ontology. The task concerns the implementation of the ARIADNE ontology extensions, known as application profiles, to specific sub-domains of archaeology and archaeological science. The work is organized in subtasks by domain. The deliverable introduces the AO-Cat and it discusses the distinction between collection and item-level records. It reports on the state of progress on the development of application profiles in each sub-domain and introduces the plans for harmonisation of the profiles at the implementation stage.

The AO-Cat itself provides a suitable application profile for sites and monument records and excavation reports (sub-task 4.4.0), as well as for individual artefacts (sub-task 4.4.7). It also appears that it will be sufficient to describe site-level information within most of the other sub-domains. However, it is anticipated that more specific application profiles will be required for other subtasks, including palaeo-anthropology (4.4.1). The most advanced application profile is an extension of the CIDOC CRM for Heritage Science. It appears that this may be adapted to cover several laboratory-based sub-domains, including Bio-archaeology and Ancient DNA (4.4.2), Environmental Archaeology (4.4.3), Inorganic Materials study (4.4.4), and Dating (4.4.5).

The sub-domain of field survey (4.4.6) may also need its own application profile, as will specific aspects of remote sensing (4.4.8), and standing structures (4.4.9), although the working group on spatio-temporal data (4.4.10) has agreed that the field is so diverse and fragmented that the first priority has to be a catalogue of geospatial services. Maritime and underwater archaeology (4.4.11) is currently on hold, but is served by AO-Cat to some extent. Archaeological fieldwork (4.4.12) is also covered by AO-Cat at site level, but detailed excavation archives would require a complex application profile, although several partners have already done work on mapping their databases to the CIDOC-CRM and work is underway on developing an application profile. The applications profiles for inscriptions (4.4.13) and burials (4.4.14) are also relatively well advanced.

The next priorities are to complete work on those application profiles that are already well advanced, to assess which sub-domains which are underway can be amalgamated and harmonised using the CIDOC CRM and its extensions, such as CRMarchaeo, and to complete the outstanding profiles, where possible. Workshops are planned to investigate how the application profiles can be implemented within VREs to be developed in D4Science, and how these will help address the research questions of archaeologists by allowing them to combine multiple datasets.

2. Introduction and objectives

This deliverable provides an initial report on the work done on ontology implementation during the first 24 months of ARIADNEplus[1], assessing it and planning the related activities for the second period, i.e. months 25-48. The activity happens primarily under T4.4, but related work also takes place under WP2 (Extending and Supporting the ARIADNE community), WP5 (Extending the ARIADNEplus data infrastructure), WP12 (data integration and interoperability), and WP14 (The ARIADNEplus knowledge management system), and these provide the focus of other deliverables either already submitted (D2.2 and D5.2) or due shortly (D12.2 and D14.1).

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[1] The ARIADNEplus project is the continuation of ARIADNE, which established the methodology and started creating the community. We use *ARIADNEplus project* or simply *ARIADNEplus* to indicate the work done in the current project and *ARIADNE* to denote the shared vision and methodology, as for example in the sentence 'ARIADNEplus relies on the ARIADNE community' which refers to the community created by the ARIADNE project and has been extended by ARIADNEplus. Reference to the former ARIADNE project results, activities, etc are denoted by explicitly referencing the 'project' e.g. 'ARIADNEplus extends the scope of the ARIADNE project'. In sum, *ARIADNE* refers to the common philosophy of *ARIADNEplu*s (project) and of the former *ARIADNE project*.

3. The AO-Cat ontology for the ARIADNE Catalogue

The ARIADNE Ontology, AO for short, is an ontology for the archaeological domain being developed by the ARIADNEplus project for the purpose of integrating the archaeological data of the ARIADNE partners into a common information space, according to the following methodology. First, a standard ontology in the Cultural Domain area, namely the CIDOC CRM, has been assumed as the conceptual backbone of AO, providing a unified and coherent linguistic and axiomatic framework to the project. Subsequently, the CRM has been specialized, under a specially devised namespace to cater to the needs of the different aspects tackled by the ARIADNEplus project[2]. The first of those specializations is AO-Cat, the part of AO dealing with the representation of the resources in the ARIADNE Catalogue. The AO-Cat has been developed during the first months of the project, and it is currently used to build the ARIADNE Catalogue. The second round of specializations are the application profiles, which are currently being developed to support the integration of the item-level data of the ARIADNE partners into the ARIADNE Content Cloud.

The distinction between collection level and item level may seem like an obvious one, but can be applied in many ways, according to how we define what we consider to be items. This will in turn depend on the specific research context and research question. For example, at the level of landscape research, each archaeological site may be considered to be an item of observation, and the collection-level record refers to the database of national sites and monuments, whereas for an artefact-based study, the individual objects may be the items of interest, and the collection-level record now refers to the database of artefacts, potentially from across several sites.

In the first phase of ARIADNE (2012-16), the ARIADNE project produced a catalogue that already included summary metadata records for archaeological sites and monuments at item level, and these were searchable via the ARIADNE portal. This approach has been retained in ARIADNEplus, and has been labelled sub-task 4.4.0. In the first phase of ARIADNE, i.e. during the ARIADNE project, we also undertook some experiments in more granular item-level integration, most notably investigating interoperability between several databases of coins held by different partners (Felicetti, Gerth et al. 2016; Aloia et al. 2017). In ARIADNEplus such developments are now the domain of the application profile.

However, it is worth noting that AO-Cat is itself an application profile for what we might regard as higher level archaeological observations. It captures the basic "What?", "When?" and "Where?" information that powers our portal search interface, and provides an adequate representation for the discovery of resources relating to archaeological sites and monuments. It has also become apparent that it provides adequate core information for other sub-domains where "What?", "When?" and "Where?" capture the core metadata and data, as in the case of archaeological artefacts (4.4.7) for example. In other cases, it can provide a collection level record for other classes of monument, such

[2] https://www.ariadne-infrastructure.eu/resource/ao/ Note that at the moment this URI does not resolve due to the fact that the project is in the process of building the ARIADNE Content Cloud. When the implementation of the ARIADNE Content Cloud will be completed the URI will resolve to the definition of the ARIADNE Ontology, and its fragments will resolve to the individual terms in the Ontology. The same applies to the URI that identifies the AO-Cat namespace, see below.

as buildings or underwater archaeological sites, although an application profile may be needed to deal with the specific research questions of the sub-domain. In these cases, the single AO-Cat record may provide the jumping off point and linkage from the discovery portal for an application profile implemented in one of the D4Science VREs, which are to be developed over the next two years. The extent to which it has already been agreed that the AO-Cat is sufficient, or where it can be used as a collection-level pointer to item-level records will be considered as progress on each sub-domain and application profile is discussed below.

AO-Cat has been already introduced in detail in deliverable D4.1. This section will therefore just summarize its key points. In contrast, the application profiles are here introduced for the first time, therefore the report will devote a significant amount of space to their description, in Section 4.

The AO-Cat defines classes and properties to represent the resources in the ARIADNE Catalogue. It uses a namespace which is a subspace of the AO namespace[3]. The main classes of AO-Cat are displayed in the following figures, which also gives the sub-class relationships amongst them.

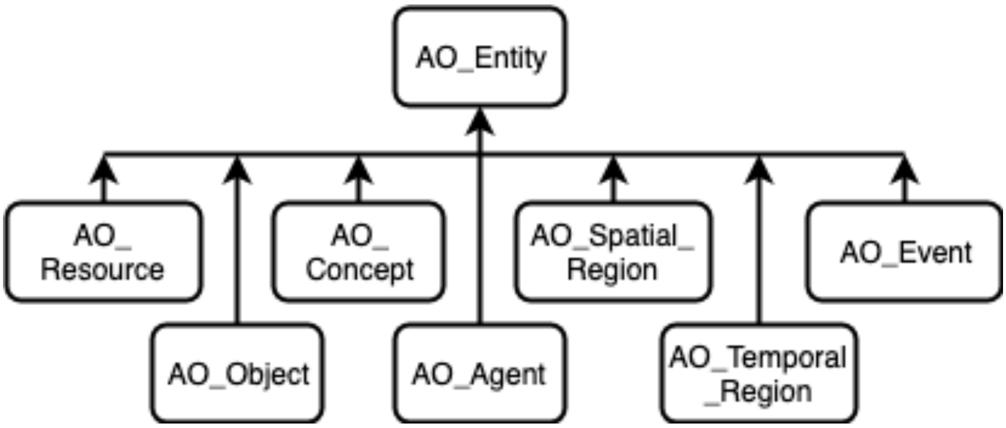

Figure 1: The main types of AO_Entiity

- **AO_Entity** is the most general class of AO-Cat, encompassing all resources that have any role in the ARIADNE infrastructure. AO_Entity is defined for capturing domains or ranges of properties that cover the whole ARIADNE information space, such as for instance the range of the is_about property.
- **AO_Resource** is the most general infrastructural resource class in AO-Cat, further specialized as shown in Figure 2.

[3] https://www.ariadne-infrastructure.eu/resource/ao/cat/ See previous note on the AO namespace.

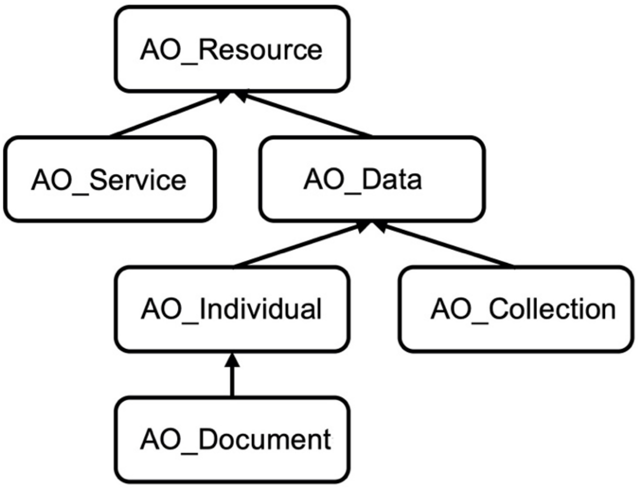

Figure 2: Key components of AO_Resource

- **AO_Event** has as instances resources that represent archaeological research activities such as excavation, discovery, analysis, classification, dating, and so on.
- **AO_Object** is defined for classifying all physical objects that are relevant to the archaeological activities, such as monuments, burials, buildings, man-made tools and so on.
- **AO_Concept** provides the topics a data or a service resource is about. These topics are grouped in three main categories (1) the ARIADNE fundamental categories, (2) the terms of the ATT Thesaurus, and (3) any other term used in the data of some provider.
- **AO_Spatial_Region** and **AO_Temporal_Region** provide representation for various types of regions in space and time, used to contextualize the events and the resources in the ARIADNE information space.
- **AO_Agent** models entities that can act, distinguished in persons and organisations.

Each one of these classes is the domain of several properties that are used to capture the salient features of the instances of a class. These features are selected based on the requirements that the ARIADNE Catalogue is meant to serve, amongst which resource discovery and interpretations are the most remarkable ones.

At present, AO-Cat includes 62 properties. The complete list of these properties, as well as their ontological features, such as domain and range, can be found in Deliverable D4.1.

4. Application profiles and other compatible models

An application profile is a set of classes and properties that can be used to model the data of a specific domain. It is therefore created for a specific purpose or, in the case of ARIADNE, for specific research domains, by selecting and grouping in a consistent manner the classes and properties of one or more existing models, rather than developing a new model from scratch. For example, we select some classes of the CIDOC CRM, others from Dublin Core etc. to define a profile, to describe scientific data at item level. We can also create 'simplified' classes that correspond (i.e. are mapped) to existing classes of other models in order to customise the model as much as possible. The AO-Cat, as described in Section 3 itself is an application profile defined for the specific purpose of creating the new ARIADNE catalogue. To maintain compatibility, new classes introduced in this way are subclasses of one or more CRM classes, from which they inherit all properties. E1 CRM Entity is the ultimate superclass for this purpose if no other class is suitable for it.

The work of creating application profiles has been delegated to 14 special interest groups, each aligned with the 13 initial sub-tasks of T4.4, with the addition of a burial special interest group in response to interest from the consortium. Each special interest group is convened by a sub-task leader drawn from the archaeological partners, supported by UoY-ADS and PIN. The groups are charged with surveying, collecting, creating and managing multilingual domain thesauri and vocabularies, as well as developing such ontology extensions for specific domains. Most have conducted online discussion via Basecamp, supplemented by online meetings.

In some cases, the working groups have decided that the AO-Cat is sufficient, without further modification and enhancement, to cover the needs of their sub-domains, even for the aggregation of 'item-level' data. In other cases, they are working to define an extension to the AO-Cat.

4.1. Palaeo-anthropology

Subtask 4.4.1, led by CENIEH and supported by UNIROMA1, aims at defining a metadata model for Palaeo-anthropology, in parallel with the systematisation of palaeo-anthropological data and the creation of a digital infrastructure for the management of the information of this domain suitable to be shared via ARIADNEplus. The data initially selected by CENIEH to be made available within the ARIADNEplus infrastructure include: Comparative Anatomy, Osteological collection, Rocks collection (Lithotec), Modern Human Teeth and Sediment data. These data are structured in different formats including photos (TIFF, JPEG, etc), Excel, free text, etc. CENIEH is also involved in the definition of the guidelines for the description of the different types of data and the way to share them with other archaeological information.

From February 2020 the sub-task was joined by researchers from University of Tübingen working on the project "The Role of Culture in Early Expansions of Humans" (ROCEEH) of the Heidelberg Academy of Sciences and Humanities[4]. Since 2008 this project has gathered ~8.000 archaeological assemblages

[4] http://www.roceeh.net/home/

from ~1700 localities in Africa/Eurasia and stored it in the ROAD Database[5]. The data comprise predominantly early human cultural and biological artefacts, as well as environmental data, which have been excerpted from scientific publications and excavation data (e.g. UNESCO Swabian Jura).

Each of these institutions uses its own data schemas and vocabularies, and organises the data according to different criteria which consequently provide different perspectives on the way in which the information in this domain is managed. This diversity is certainly a source of inspiration to ARIADNEplus and suggests innovative ideas on how to aggregate complex information like this and how an application profile to model it should be designed.

In addition to having to deal with the extreme heterogeneity and complexity of the palaeo-anthropological data, this subtask has also suffered some delays due to some organisational issues within CENIEH, both with the process of recruiting the staff to deploy on ARIADNEplus activities, and for the preparation of the IT infrastructure to host their paleoanthropological data. However, CENIEH has already started the data analysis process and established a specific collaboration with the IT Department of the University of Burgos to enhance its infrastructure and promote the analysis of its data and vocabularies, in order to speed up the definition of a shared model for ARIADNEplus which will be completed within the next period. ROCEEH, despite having recently joined the project, has already completed the data analysis of the ROAD database and provided AAT and PeriodO mappings for the description of their data in the ARIADNE Catalogue. Within the next period this will certainly result in a valuable contribution to the definition of the application profile for this domain.

4.2. Bio-archaeology and Ancient DNA

Subtask 4.4.2, led by FORTH-IMBB and supported by UoY-ADS, OEAW, AU, HNM, UNIROMA1, DANS, RUG, and DGPC aims to define the application profile for bio-archaeology and ancient DNA data, building mappings from existing data schemas to it, for subsequent integration in the ARIADNE Cloud.

During the first half of the project, FORTH-IMBB in close collaboration with FORTH-ICS worked on the definition of a model that would describe the ancient DNA wetlab services. We analysed projects currently running in the aDNA laboratory facilities of FORTH-IMBB. Each project is initially described as an AO_Collection since it is an aggregation of resources. For the description of the AO_Collections FastCat was used. The properties of AO_Collection were found sufficient to describe aDNA projects at a high abstraction level. Then in order to describe in more detail the aDNA wetlab services we used classes and properties from CIDOC-CRM and the family of its compatible models. In section 6 we present a tentative modelling approach in detail.

4.3. Environmental Archaeology

Sub-task 4.4.3 is led by Umea University, a linked third-party of SND. Umea hosts the international SEAD database, which includes information about a range of environmental data, including insects, pollen, seeds, as well as some scientific dating information. In December 2019 they circulated a survey,

[5] http://www.roceeh.uni-tuebingen.de/roadweb/smarty_road_simple_search.php

as the first step towards an application profile for environmental data, although this revealed that few partners have comparable data. This sub-domain is challenging as an appropriate level of data integration needs to be defined and we need to understand what is item level in an environmental archaeology context, given it is not feasible to be a single seed, insect, or grain of pollen. The issue of vocabularies is also complex as there are multiple overlapping vocabularies, and none are comprehensive. There is also a need to link to external databases, including those managed in other domains, such as Neotoma, with close links with natural and geological sciences.

The SEAD database follows a standard relational model whereby multiple analyses may have been undertaken at each archaeological site. The site table is fairly well covered by AO-Cat, and catalogue level data can be produced by mapping SEAD to the AO-Cat. However, at the level of specific analyses there is a need for a more specific application profile, although a preliminary investigation has suggested that, with some small modifications, the application profile being developed for laboratory analyses in the physical and chemical sciences (See 4.4. and 4.5) may be adequate, possibly with minor adjustments. The target for the next phase of work in this sub-task is to investigate this further, which is expected to be completed in a reasonably short time.

4.4. Inorganic Materials Study and
4.5. Dating

During the first half of the project, the partners of subtasks 4.4.4 (Inorganic Materials Study) and 4.4.5 (Dating) set up a working group for scientific data aimed at defining an ontological model that would serve as an application profile for ARIADNEplus and at the same time as a conceptual framework for scientific data still lacking a metadata model. The working group is composed by partners from INFN, CyI, HNM, PIN, OEAW and LNEC.

As a result of the activities of the working group, the requirements and scenarios for the scientific domain were defined and the first draft version (0.9) of CRMhs, a CIDOC CRM and AO-Cat compatible ontology for scientific data, has been released together with the related documentation, which includes the conceptual description of the model and the detailed scope notes of its classes and properties.

The CRMhs model is presented in Section 5 of this document as a case study for application profiles definition. The scientific data requirements document has also been published within ARIADNEplus to be used as a template for gathering requirements and defining scenarios for other application profiles[6].

For the next period, an activity of harmonization of CRMhs with the model proposed for bio-archaeology and ancient DNA (see 4.2) is planned, which will lead to the definition of a complete framework for the description of all the data related to scientific activities that ARIADNEplus aims to integrate.

[6] https://docs.google.com/document/d/1PFqQlb1rVNnVmdlLKwDdzs2Kp6H1ScVA3UHSM7lCj48

4.6. Field Survey

The task leaders (RUG) have focussed their work so far on survey data derived from field-walking, although we should note the potential overlap between this sub-task and 4.4.8, and metal-detector surveys considered in 4.4.7. RUG have noted an unfortunate lack of re-use of field-walking survey data and conclude that CIDOC CRM provides the best long-term solution for this, along with greater harmonisation of field and documentation protocols. Their review of current practices has highlighted that survey archaeologists do not yet comply with the FAIR principles in archiving their data. Currently archived and accessible survey datasets in ARIADNEplus partners DANS and UoY-ADS only form a small minority, and although these are Findable, Accessible and largely Interoperable, they do not comply with the Re-usability criterion, which requires higher standards of documentation.

Only the data owners have the knowledge and expertise to produce such documentation, e.g. by adding extensive metadata to their archives, after the fact. Perhaps more importantly, substantial data re-use could be achieved in future more easily if field survey practitioners could agree to adhere to sufficiently high data documentation standards. The best current overview of field walking surveys taking place in the Mediterranean zone is provided by Fasti Online Survey, managed by ARIADNEplus partner AIAC. Fasti Online Survey contains basic metadata on circa 120 survey projects in the Italian peninsula, and it would only seem logical that those data should be made available for large-scale analysis. However, many of these projects have only published their datasets partially (e.g. providing site gazetteers), or not at all. Few of them have published their data fully, and even fewer have supplied a digital data archive to a repository.

Working with Leiden University, RUG have published their findings in the AIAC FASTI online journal (de Haas and van Leusen 2020). They have started the process of developing an application profile by defining the required concepts, and propose to set up a CRM special interest group to develop a CIDOC extension, concluding that “Although the process of formally agreeing a CIDOC CRM extension for field survey is a slow one, we believe a global solution to the problem of comparability is worth pursuing over a local, temporary one”. They propose that survey data could then be converted to RDF and uploaded to the ARIADNEplus triplestore, using the CRM application profile.

4.7. Archaeological finds made by general public

This task aims to develop the integration of finds recorded by members of the public (mainly metal detector finds). This will be achieved through facilitating the harvest of data from the different national user driven recording schemes, which already cooperate under the umbrella of the European Public Finds Recording Network (EPFRN): DIME (DK), MEDEA (Flanders), PAS (England and Wales), PAN (The Netherlands), SuALT (Finland) and others. These schemes all aim at the inclusion of archaeological objects found by members of the public in the archaeological record and at making them publicly accessible for researchers and the general public alike. It should be noted that this kind of activity is not allowed in some countries where any kind of organized archaeological survey – including amateur activity – is subject to permission by governmental archaeological offices, and is usually granted only to professionals. In these cases, casual discovery of archaeological finds must generally be immediately reported to the authority and the objects found, if collected, must be delivered to them. Therefore, no such data will be available for such countries that include most Southern European states.

In much of Northern Europe and Scandinavia, on the other hand, the development over the past decades of databases for finds made by members of the public is closely linked with more general tendencies towards inclusive approaches in heritage management and the paradigm of digital humanities. Hence, task 4.4.7 is closely linked to task 16.5 – ARIADNEplus for public/community archaeology, which aims at investigating trajectories of public inclusion and participation and at demonstrating the added value of ARIADNEplus for non-professional archaeologists, through incorporation of principles of citizen science and crowd-sourcing.

In its focus on metal detector finds produced by members of the public, the task is rooted in the unique legal situation and policy approach in specific countries (DK, UK, NED, FIN, Flanders). Here, the 'official heritage sector' has a permissive or even supportive/facilitating approach.

The working group, led by AU, has concluded that the AO-Cat is sufficient to adopt as the ontology for 4.4.7, but that more fine-grained vocabularies need to be developed to achieve interoperability at a fine level for finds classification, and they propose that this will be achieved via extensions to the Getty AAT. A workshop planned to take place in Aarhus University, in collaboration with the SEADDA COST Action has had to be postponed due to Covid-19, but will be resumed in the next stage of the project.

4.8. Remote Sensing

Sub-task 4.4.8 is in charge of implementing the application profile for data from airborne LiDAR and satellite data as well as aerial imagery, building mappings from existing data schemas to it, for subsequent integration in the ARIADNE Cloud. It is also in charge of preparing thesauri and vocabularies for this domain. The sub-task scope also includes geophysical surveys. It is led by ZRC-SAZU and also involves ARUP-CAS, HNM, CARARE, and UoY-ADS. The sub-task leaders carried out a survey of what data was held by partners between Jan and March 2018. The results of the survey demonstrated that three data types were held: (geophysics, oblique aerial photography and lidar/satellite data) recorded on two levels (final reports and as full data). The working group agreed that the reports were adequately covered by the AO-Cat, and that aerial photography could be dealt with as GIS within 4.4.10. The outstanding area was therefore the ingestion of LiDAR derived data (beyond final reports). The working group planned to hold a joint workshop with the SEADDA COST action but this has had to be put on hold because of Covid-19, and planning will be resumed in 2021.

4.9. Standing Structures

From March-May 2019, the sub-task leader, LNEC, undertook a survey of which partners held data concerning standing structures information. During this it became clear that most data was just held at collection level, where the AO-Cat as applied to sites and monuments was adequate for data aggregation. Some differences have been identified relating to specific concepts and semantics (especially related with events and activities), but globally the model already developed seems to be suitable.

Nevertheless, there are some examples of information about buildings and physical infrastructures which might be suitable for item level integration. The representation of the physical and functional characteristics of standing structure components, integrating their relations through space and time, is essential for operating and maintaining these assets. International standards on frameworks and classes should be considered for the model conceptualization at the item level. Particularly in terms of materials characterization analyses, the harmonisation with the Task 4.4.4 application profile has been accessed and considered feasible.

LNEC have identified the relevant technical terms and periods for mapping to Getty AAT and Period0, contributing to the thesauri and vocabularies for the Standing Structures domain, and will continue to work towards an application profile for which the existing CIDOC CRMba extension may be relevant.

4.10. Spatio-temporal data

The goal of subtask 4.4.10 is to investigate the possibilities of integration of geospatial databases (GIS datasets) into the ARIADNE Portal at item level. Integration on the collection level is covered by other subtasks, esp. 4.4.0 – “Sites and monuments inventories and event records” and is dealt with by the AO-Cat.

During March-May 2019, an initial assessment of information on available datasets was conducted among concerned partners by ARUP, as task leader. Of 13 partners originally included in the subtask (ARUP-CAS, PIN, OEAW, PP, NIAM-BAS, HNM, FI, IAA, MIBACT-ICCU(ICA), DGPC, SND(UU), KHM-UO, DANS-KNAW), answers were provided by 6. As an addition to original plan, answers were given as well by UoY-ADS.

Among partners there are four (HNM, UoY-ADS, DGPC, FI) who systematically collect GIS datasets derived from archaeological fieldwork. Another three partners (PP, SND, ARUP-CAS) collect data on the research project basis, but unsystematically.

There are several national standards for data description in place (Hungary, Iceland, Sweden). PP plan to make their datasets compliant with CIDOC-CRM, while other data stay non-standardized (UoY-ADS, DGPC, ARUP-CAS).

Geospatial features representations in GIS datasets are usually variable, without any methodological specification (UoY-ADS, FI, SND, ARUP-CAS, DGPC). The only exceptions are HNM (at a national level) and PP (at an institutional level), with a transparent strategy of geodata classification and representation.

Temporal (chronological) attributes are often present in the data, however on different levels. Item level temporal data are usually present in all datasets stored by partners, but only the datasets of

HNM and PP are described according to a shared standard. In other datasets, temporal data are included according to the decision of the data provider and it seems impossible to collect or harmonize them automatically. DGPC, UoY-ADS, SND and (partly) ARUP-CAS are able to provide standardized temporal data on the collection level.

There are plenty of formats used for the geospatial data storage by partners (SHP, DWG, DWF, GeoTIFF, GeoJSON, TIN, GRID, KML). ESRI shapefiles, GML and PostGIS databases seem to be prominent options chosen for the data handling as well as for the long-term preservation. Three partners are ready to publish (or are publishing already) their geodata as web services (WMS/WFS) using GIS servers (DGPC, FI, ARUP-CAS).

With only one exception (FI), all the datasets are described by metadata, which usually follows institutional (UoY-ADS), national (HNM) or international standards (DGPC, PP, SND). Further systemization of the geospatial data during the ARIADNEplus project is planned only by DGPC and PP, and considered by FI and ARUP-CAS.

Two partners expressed a willingness to include their geospatial data on the item level (PP, ARUP-CAS), with FI possibly joining them later. Due to various reasons, all the other partners are able to provide their data on the collection level only. The schedule for data provision falls in the second half of the project (DGPC, FI, PP, ARUP-CAS, UoY-ADS), with SND having data ready for provision and HNM waiting for further clarification (with HNM also noting that their spatial data cannot be publicly shared on the item level due to the official restrictions).

In summary, the survey revealed a vast diversity of data on the item level as well as an intersection with other subtasks (e.g. 4.4.14 for burial data). The focus of subtask 4.4.10 was therefore updated, aiming for the integration of the archaeological and archaeologically relevant online geospatial data services in the ARIADNE Portal using the AO-Cat. Although the solution for spatial data may seem to be simple compared with other application profiles, it builds on existing standards of data exchange proven by international and interdisciplinary practice. Any further integration would need a harmonization of datasets involved, which is, however, already dealt with in relevant topic-based application profiles. In subtask 4.4.10 a different approach had therefore been adapted to increase the discoverability of both:

1. **Archaeological data** which are available in standardized form and easy to integrate with other spatial data for any use-case even outside archaeology.
2. **Proxy-data** (e.g. elevation data, historical climate data, hydrology data, old maps etc.) useful for archaeologists in specific fields and regions, which can contextualise their own research data and are made available by non-archaeological service providers.

Creating an interactive catalogue of such geospatial services available online will greatly enhance compatibility and increase the value of the ARIADNE Portal not only for archaeologists but also for other scientific domains (esp. for environmental research, geosciences, heritage management, etc.) in which online published geospatial layers are a common way of data exchange.

4.11. Maritime and underwater archaeology

Sub-task 4.4.11 is led by the DGPC, who are responsible for managing the cultural heritage of Portugal, and have special expertise in maritime archaeology. In March 2019 they initiated a survey of data sets and existing data standards but it became clear that there are few other partners with relevant data. Many aspects of maritime archaeology may be covered by AO-Cat and can be treated as sites and monuments data, so further investigation on whether there is a need for a specific application profile has been put on hold until the second half of the project. In the meantime, UoY-ADS has conducted a data audit of all maritime and marine heritage data held by the UK nations.

4.12. Archaeological fieldwork

Sub-task 4.4.12 is concerned with the very broad area of archaeological fieldwork, and is led by INRAP, the state archaeological service for France. The first task was to clarify exactly what is meant by "Archaeological Fieldwork" in ARIADNEplus in order to avoid overlaps with other sub-tasks. It was agreed that the scope of 4.2.12 does not include field-walking (see 4.4.6), geophysics (see 4.4.8), building recording (4.4.9), or maritime and underwater archaeology (4.4.11), although it has links to each of these other sub-tasks. It was also agreed that it excluded item level records of field events ("there was an excavation at this date on this site and this is the grey literature reports ") which fell under 4.4.0, and was adequately dealt with by the AO-Cat. The working group therefore resolved that the sub-task should focus on "full" digital excavation archives of data. These might include databases and spreadsheets of layers, digital photographs of the excavation, CAD and GIS etc, although it was noted that aggregation of GIS was best undertaken within sub-task 4.4.10.

Many of the archaeological partners contribute to the sub-task, including OEAW, BUP-DMS, AMZ, CYI, RGK, PP, IAA, AIAC, MIBACT- ICCU, KHM-UO, DGPC, UB, SND, ARUP-CAS, and UoY-ADS, and from an initial survey it became clear that many partners held such full excavation archives. For example, ARUP hold data from their own fieldwork, with common vocabularies, as well as digitised versions of photographs and plans of earlier excavations. At CNRS, the MASA consortium hosts the ArSol database (http://arsol.univ-tours.fr/): the excavation data recording system used by the Tours team. This database contains currently 6 archaeological excavations carried out in Indre-et-Loire (France). They also host the data from the Kition-Pervolia site in Cyprus. In Israel, the IAA manages DANA (Digital Archaeology National Archives) which documents all archaeological field work done at the Israel Antiquities Authority, including geographical, alpha-numeric and photographic documentation in one system. The data is structured and uses an internal IAA thesaurus. KHM-UO leads the Norwegian national ADED-project (Archaeological Digital Excavation Documentation). ADED will create a common platform for detailed excavation GIS-data in Norway, and will migrate existing excavation documentation to this platform, completing in 2021 from when they will be able to contribute ADED datasets to ARIADNEplus. UoY-ADS holds over 1000 excavation archives of which over 200 include databases of layers and finds, as well as CAD and GIS plans. Collection level records will be provided under sub-task 4.4.0. More detailed data could be provided where there is a research use case.

Several partners, notably CNRS, KMH-UO, SND (Lund) and PP have experience of using the CIDOC CRM to try to model raw excavation data and have concluded that existing extensions of the CRM, including

CRMarcheo and CRMdig, provide the basis for an application profile for fieldwork data. In the next phase of the project a smaller working group, led by PP, is focussing on providing some exemplar mappings.

4.13. Inscriptions

The implementation of an application profile for the integration of data related to inscriptions, graffiti and other similar materials is the main purpose of task 4.4.13. Information on inscriptions is provided to ARIADNEplus by UB, UoY-ADS, AMZ, CYI and SND, who have formed a small team for the development of the related application profile with support by PIN and CNR. This is a heterogeneous group of data sets and the metadata models of many of these partners already include fields/classes for the documentation of inscriptions, graffiti, marks, rock art and other relevant data sets. Although work on the applications profile is well advanced it is not yet complete, but in Section 6 it provides our second case study of work in progress.

In Section 6 we present some general considerations regarding the fundamental requirements of this domain, some specific scenarios already modelled in ARIADNEplus and the identification of some relevant entities already defined in existing domain ontologies developed for the modelling of this type of data. The formal definition of the classes and properties of the application profile for inscriptions will be finalized in the next phase of the project.

4.14. Burials

This has been an active group, led by OEAW, with participation from ARUP, ZRC-SAZU, PIN, and UoY-ADS. Mortuary archaeology consists of a series of research activities and analyses carried out either directly on archaeological evidence containing human remains or contexts that are interpreted to relate to the disposal of the dead or on documentation of and finds from such contexts. The aim is to acquire information concerning many aspects of past societies, such as ways of disposal of the corpse, funerary practices, identity, migration, social composition.

Datasets from partners (ARUP, ZRC-SAZU, UoY-ADS**,** HNM**)** were analysed in the spring/summer. It was found that the datasets from this domain are usually generated at different stages of the workflow, involving the participation of different actors with various roles and the use of specific devices and software. All these elements are considered relevant in order to define adequate metadata for scientific datasets. The stages at which datasets may be created include: datasets generated in the field with no or only limited post-excavation analysis; datasets generated as results of workflows based on fieldwork documentation (digital datasets, or, in previous times analogous documentation) and analysis of physical objects (human remains and objects that were found with them, as well as samples taken from both); datasets that synthesise/aggregate mortuary data.

The group has defined a preliminary application profile, which is mapped to CIDOC CRM entities. They have agreed that collection level records - in their case one per cemetery/monument - are adequately covered by AO-Cat, which will provide the overall extent of a cemetery (or at least a centroid point for it), and its date range, and maybe some sub-categorisation, following AAT e.g. 'cremation cemetery', 'mound burial' etc. In some cases, the attributes of Item level records - individual graves - are also described in AO-Cat, for example each grave also has its own 'micro-co-ordinates', and may have a more restricted date range than the cemetery as a whole. However, other attributes have been defined in the application profile, e.g. age and sex of the individual and other skeletal attributes; grave-goods; grave structure and position of the body/skeleton e.g. supine, extended, flexed etc. The group have also begun to consider the research questions that can be addressed by the aggregated data, and plan to discuss how this could be supported by a dedicated VRE in D4Science at a workshop in January. There are links with other application profiles, most importantly bioarchaeology (4.4.2), individual artefacts (4.4.7), and scientific dating (4.4.5), which will be resolved at the harmonisation stage (see Section 7.1).

5. Case Study 1: CRMhs and scientific data

This section describes in detail the CRMhs model, a CIDOC CRM and AO-Cat compatible ontology for documenting heritage science activity and all the entities of this discipline. Heritage science is an interdisciplinary branch of research applied to the cultural heritage which uses a wide range of scientific activities to support conservation, access and interpretation of cultural heritage. Heritage science derives its methods from a number of fundamental sciences, such as physics, chemistry, biology, and more and consists of a series of research activities and analyses fostering the use of highly sophisticated techniques and high precision instruments, intended to avail a better reading of objects, materials, artefacts and artworks of cultural and historical significance and a deeper understanding of their physical composition, dating and geographic provenance.

A scientific approach to the study of a work of art is indeed essential in order to address all those questions that cannot be answered just by historical/artistic assessments, and may help for instance for:

- providing indications on artefacts' conservation state in order to plan the correct restoration/conservation procedures
- determining materials and production techniques
- studying the provenance of raw materials in order to retrace ancient trade routes
- dating organic or ceramic material
- giving indications about authenticity

The international panorama provides many examples of models oriented to the description of information produced by scientific research, some of a general nature, others more specifically oriented. However, there is no conceptual model specifically designed for Heritage Science, able to capture the peculiar relationship between this branch of science and the world of Cultural Heritage and to fully express all the complex relationships between them. The main feature of Heritage Science, in fact, consists in combining the strict analytical procedures typical of the scientific world, with the humanistic investigations.

CRMhs was created with the aim of:

- Providing a conceptual model for the creation of digital databases and archives containing scientific research results and their interpretation, in particular for institutions still lacking such archives but wishing to systematize their documentation and create digital libraries for their laboratories.
- Providing a tool for standardization, sharing and integration of scientific data for institutions and laboratories already in possession of digital archives and willing to share their knowledge with the scientific community and to establish cross-disciplinary information integration and interoperability with the Humanities and Cultural Heritage disciplines.

For both of these objectives, CRMhs shares the data modelling philosophy of CIDOC CRM and the FAIR principles[7] for accessibility, integration and (re)usability of digital data. These principles have been

[7] https://www.go-fair.org/fair-principles

constantly used both to outline the conceptual basis of the model and to define its classes and properties. In the ARIADNEplus perspective, all the entities defined in CRMhs are fully compatible with the AO-Cat model and therefore can be used, in combination and in harmony with it, as components of the ARIADNE Ontology.

5.1 CRMhs conceptual background

Heritage Science consists of a series of activities aimed at improving the historical and material knowledge of cultural objects (archaeological finds, artistic and architectural objects, etc.) by means of scientific analyses of the objects themselves or of parts of them.

Scientific analysis and measurements represent the core of the discipline and can be described as a series of activities, coordinated and carried out according to precise and rigorous scientific criteria, the results of which, once codified and interpreted by the experts, allow to derive new knowledge about the investigated objects. Research activities in Heritage Science can be financed, supported or promoted by various kinds of initiatives, both public and private, aimed at a specific purpose and within which scientific analyses occur.

The tools and techniques that Science makes available for the investigations of Heritage Science are manifold and present considerable differences in the methodologies of execution. Many of these techniques are composed of articulated series of coordinated activities, each of which is essential for the reliability of the final results, and which include, for example, conservation and preparation of samples (also with the use of specific materials, elements and substances); specific and adequate instrumentation; tools for the rendering and interpretation of raw data, such as elaboration and calibration operations performed to consolidate and review the obtained results. It is important to note that these activities can take place not only within the laboratories of the institutions that usually deal with Heritage Science but if necessary, also in the places where the investigated objects usually reside (eg museums, private collections, archaeological sites and so on). This is very common especially in case the objects are found to be non-transportable due to their size or other particular physical or environmental characteristics that make them fragile or difficult to move.

The indications on the ways in which the analyses are performed are usually defined in a rigorous way by a series of research protocols that provide all the details necessary to make the analyses scientifically valid and effective and guarantee their repeatability. Therefore, it is essential to describe scientific activities in detail, capturing their essence and precisely defining the sequence in which they take place, to produce profitable and complete documentation of how the analyses were carried out to guarantee the reliability of the resulting data.

The results of scientific observations and measurements are usually reported in paper format or, more frequently, recorded in one or more files of various kinds, created manually by scientists or automatically generated by the tools used for the investigations. These files typically have different formats and contents (they can be, for example, numeric files, Excel documents, database tables, image files, textual reports, etc.) and are usually archived according to the specific regulations of each laboratory. One of the purposes of the ontological model that we present here is to provide a conceptual grid to describe these files, their content and the whole process that led to their creation in a coherent way, as well as indications for building structured digital platforms to guarantee their efficient archiving, easy retrieval, sharing and reuse.

Another fundamental element to be taken into account is constituted by the investigated objects, of which it is essential to know the history, provenance, details of production, composition, circulation, style, geographical and temporal data and all other information usually derived from the Cultural Heritage world.

Study objects can be investigated according to various modalities, based on the techniques used for the specifically chosen analysis: non-invasive techniques such as XRF, for example, allow exploration in whole or for specific areas of an object without the risk of damaging its surface or altering its chemical-physical composition. Other types of analysis (such as, for example, radiocarbon dating) require, instead, the extraction of samples which are most often destroyed or made unusable during the analysis process.

In the case of analyses conducted on fragmentary objects, it may be relevant to acquire information on the original objects of which the investigated ones are portions or parts. Of fundamental importance, especially for archaeological finds, human or animal biological remains, is also the knowledge of the environmental context in which they were found and/or acquired, and the awareness of all the procedures according to which they were preserved and kept up to the time of their analysis: in many cases, the absence of this information risks compromising the quality of the results.

Study objects, their parts and the samples derived from them, usually constitute the *trait d'union* between Humanities and Heritage Science and make the presence of standards for the description of data fundamental so that the information produced by these disciplines, apparently so distant, can interconnect and communicate.

Analyses are typically conducted with the participation of many actors, whose work is important to be detailed. In fact, various institutions or parts of them are involved in the research process, such as: public or private institutes and their departments, universities and faculties, academies and their branches. Individual people also take active part; there are, for instance, scientists and technical operators in charge for preparing or transporting the instrumentation, set up infrastructures and environments, prepare samples, calibrate the tools, set up the software, perform the measurements, process the results and so forth.

Other institutions and people indirectly connected with scientific activities, but equally relevant in the context of their performance, are those linked to objects in various ways, such as: museums, private collections or other objects' owners or holders, archaeologists from whom the artefacts were found, scholars and other researchers interested in studying them. All of these subjects and their roles must be described and detailed appropriately.

5.2 Scientific data workflow in ARIADNEplus

The variety of techniques, objects, tools, places and people involved makes Heritage Science a very complex discipline, full of very changing contexts and situations. As an example of how a typical workflow might look, this section outlines a possible scenario of scientific analysis applied to archaeological investigation

The case study comes from the ARIADNEplus project and can be outlined as follows:

1. The starting point of the process is usually the activity of collecting objects and samples from their original archaeological site or context. It is essential, at this stage, to record the exact place or context from which the materials come, together with the environmental conditions and the collection procedures, in order to guarantee optimal analysis conditions and obtain consistent and reliable results.
2. Subsequently, the materials are brought (usually by the archaeologists) to the laboratories for analysis. Sometimes, information about the various transfer procedures is available and can be added to the metadata. The various observations and measurements can take place directly on the various materials or after a preparation process which may include several successive (and sometimes complex) preparation stages, especially for the samples.
3. Once the objects and samples have been properly prepared, the analysis is carried out by the researchers using the appropriate procedures (i.e., research protocols) and instrumentation. A series of digital information is generated as a result of each analysis.
4. The results obtained can be integrated, revised or corrected by means of standard tools and software to increase their precision and truthfulness. For example, after a C14 analysis, various calibration curves are used to refine measurement results according to the different conditions of the atmosphere over the centuries and their modifications over time.
5. The resulting datasets are archived and made available to be examined by the experts who analyse them and, through hypothesis and interpretations, acquire new data for integrating their studies.

Figure 3 provides a graphical representation of the process outlined above:

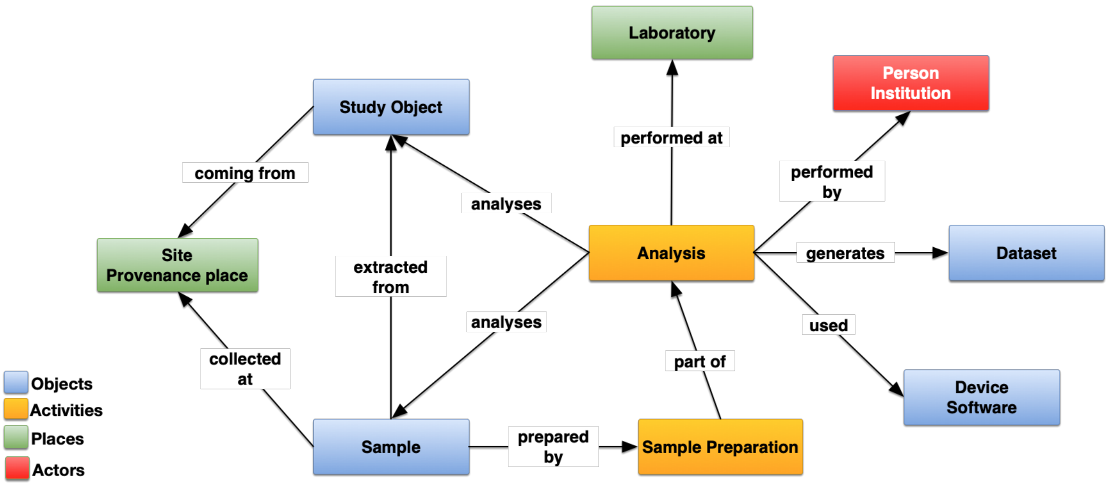

Figure 3: Heritage Science workflow for archaeological research

Workflows of this type can be defined for each of the scenarios defined for Heritage Science combining the various conceptual elements involved in different ways and linking them, according to the needs, by means of specific relationships. The CRMhs model aims to provide the conceptual building blocks to allow the efficient modelling of each scientific activity and build tailored schemas for each type of analysis.

5.3 Entities of the scientific domain

This section provides a general overview of the main entities in CRMhs and the modelling principles, inspired by the conceptualisation of Heritage Science provided in previous sections, that were used to define them. All the details of the mentioned classes and properties, including their mappings to the CIDOC CRM ecosystem and the AO-Cat model, are illustrated in detail in the Appendix of this document.

5.3.1 Events and activities

Scientific analyses and measurements represent the core of the Heritage Science discipline, being a series of activities coordinated and carried out according to given rules and criteria. CRMhs, thus, provides a series of entities capable of describing in detail scientific (and non-scientific) activities and the way they are interrelated.

Activities

The HS_Activity class is the top class for modelling any type of activity in CRMhs. It has been essentially defined to provide common properties to all its subclasses and to be used in case these ones resemble too specific to represent collateral events, such as: instrumentation transportation and preparation, environment arrangement and set up, recording and archiving of results and so on.

Analyses

Its direct subclass is the HS_Analysis class, defined to model specific activities consisting of scientific observations and measurements performed on objects or samples by means of specific instruments, in specific places (e.g., laboratories, museums) at a given time. Analysis can be of different types, i.e. non-destructive, when performed using non-invasive techniques, or destructive, e.g. when carried out on samples whose analysis requires their destruction.

Preparation of samples

The HS_Sample_Preparation class is another subclass of HS_Activity. Its purpose is to model a typical activity of the Heritage Science world, consisting of a series of procedures aimed at preparing the samples for the analysis. The sample preparation actions can often be seen as sub-activities of the main analysis (such as in the case of C14) which can result in the modification of the original sample or even the production of new samples on which the actual analyses take place.

Projects

Finally, the HS_Project class was defined to describe collaborative initiatives, undertaken over a period of time by teams of actors with the intention of performing a defined program entailing the support of a number of analysis and other scientific activities Examples of projects are the ARIADNEplus and the E-RIHS initiatives.

Figure 4 presents the hierarchy of activities in CRMhs.

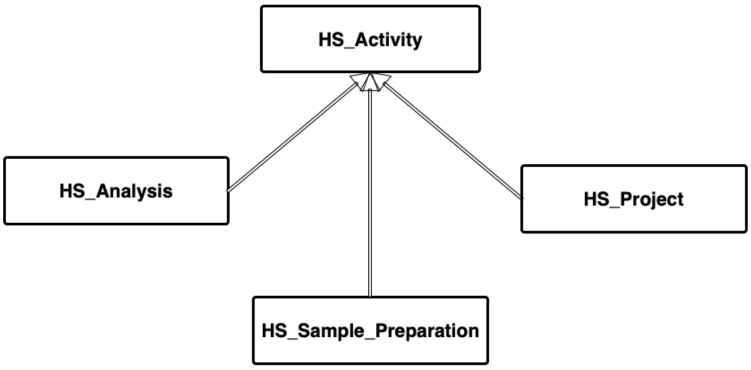

Figure 4: Hierarchy of the activities in CRMhs

CRMhs provides specific properties to outline typical traits of the research activities, such as the times (has_start_date, has_end_date) and places (was_performed_at) in which they were carried out, the equipment used (used_device, used_software) and the people and institutions involved (had_participant, was_performed_by).

5.3.2 Physical and digital objects

Heritage Science deals with a great variety of physical and digital objects that interoperate with each other during various analytical activities. Here too, as for events, CRMhs provides a high-level class (HS_Object) that provides common properties to all subclasses and can be used for generic entities.

Study objects

The objects to be studied are naturally central to the domain. CRMhs therefore provides the HS_Study_Object class to model physical things, material substances, artefacts or parts of them investigated by scientific analysis.

It is of particular importance to keep track of the origin and provenance of these objects and materials, the conditions under which they were removed from their original contexts, the methods employed for their preservation and preparation for analysis, in order to properly relate the results of the scientific investigations with their original contexts.

Samples

Samples are particular cases of HS_Study_Objects, being them physical portions of matter intended to be representatives for the objects or the environment to be analysed. They usually include: pieces of artefacts, portions of inorganic materials, fluids and organic materials e.g., bones, tissues etc. Thus, the HS_Sample class, subclass of HS_Study_Object, is provided to model them. As in the case of the study objects, keeping provenance information is fundamental also for samples. Preserving a persistent link between a sample and the artefact from which it was extracted is equally important.

Objects' parts and portions

HS_Study_Object also comes with another subclass, the HS_Study_Object_Portion class, intended to deal with specific objects' sections or portions, in cases where the scientific analyses take place on parts rather than on objects in their entirety.

Datasets

Datasets are digital objects containing the outcomes of the various analyses. The HS_Dataset class is provided to model this kind of objects. A dataset usually contains scientific results and/or their interpretation. A single analysis can generate more than one dataset. They can be typically generated automatically by the software running on the devices used for scientific measurements, or manually by scholars, for example as resulting from the specific observations or interpretations made by them on the analytic results.

Datasets can be composed of single files, sets of documents or folders, compressed archives and so on. The format and the content of the files included in the datasets can vary significantly according to the analysis/device by which they were generated: e.g. they can contain numerical values resulting from measurements, graphic representations, images, 3D models, textual descriptions.

Devices, components and software

Devices are mechanical or digital instruments used to perform analyses and scientific measurements, represented in our model by the HS_Device class. A device can often be composed or equipped with special components (modeled by means of the HS_Device_Component class) that enhance or adapt its use for a specific measurement. Being very specific tools, these kinds of objects are usually associated with specific types of analyses and involve the use of specific software (HS_Software class). One or more devices and software can be combined to perform analyses or sample preparation activities.

Figure 5 provides an overview of how objects are modelled in CRMhs (double arrows indicate IsA relations between classes).

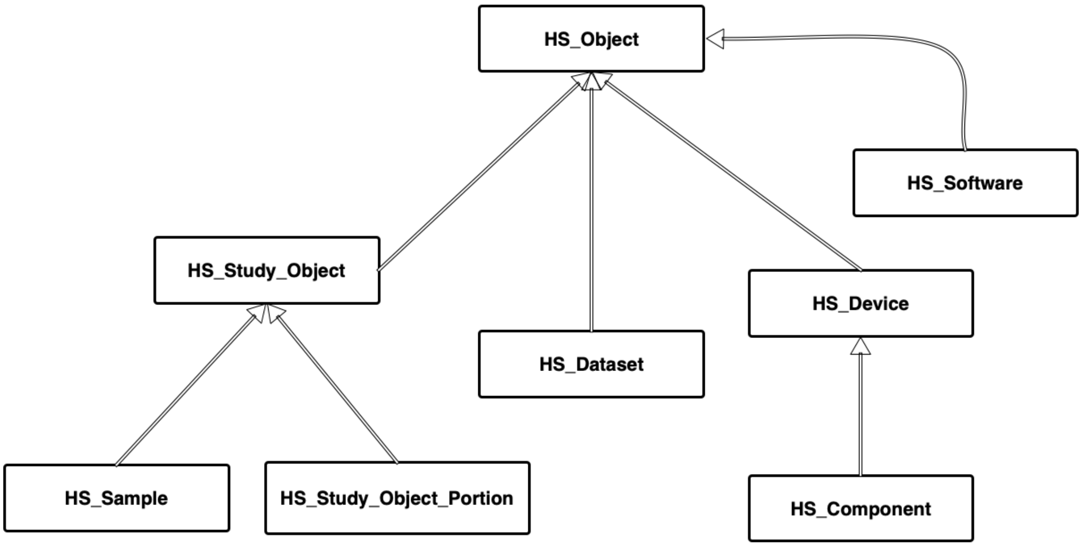

Figure 5: The hierarchy of activities in CRMhs

Activities and objects

In any ontology it is fundamental not only to define the various conceptual components of the domain described, but also to outline the ways in which these components interact with each other. The relationships between scientific activities and study objects are fundamental in Heritage Science. In CRMhs they are expressed through appropriate relationships that link these fundamental elements together.

Figure 6 shows how it is possible to describe, through the use of the specific properties provided by CRMhs, the way in which scientific activities take place with respect to the various physical objects on which they occur or which are used by them during their performance. In Heritage Science, datasets represent a special case because they usually come from the outcome of an analysis and contain its results. The produced_dataset property is used to outline these features.

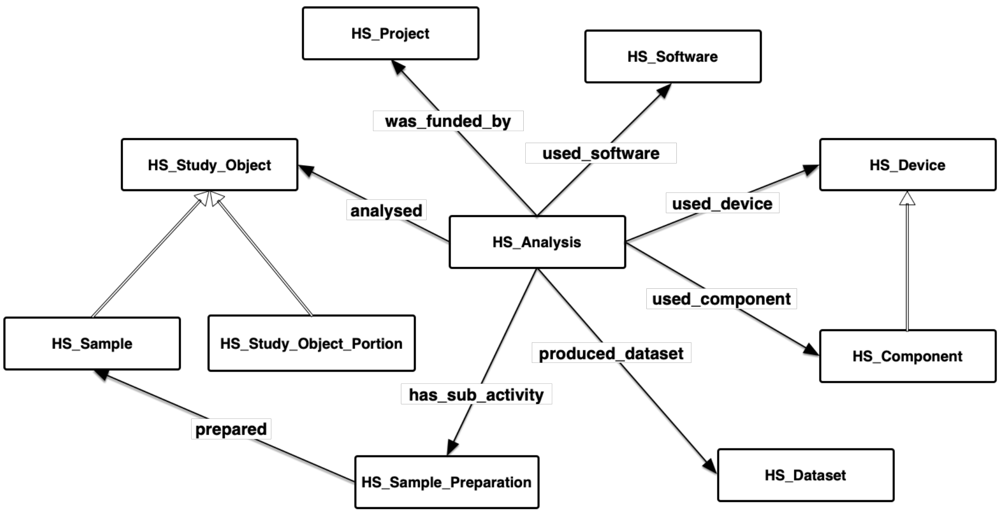

Figure 6: Activities and objects in CRMhs

Also, for objects there are specific properties in CRMhs to indicate their composition (is_made_of), the author or creator (was_created_by), the current location (has_location), the origin and provenance (was_found_at), the dating (has_period). The is_part_of property is used to state part-whole relationships between objects.

5.3.3 Institutions and people

Actors include institutions, groups and people involved in various ways and with different roles in the activities of scientific observations and measurements. CRMhs provides three classes to model actors: HS_Institution, to describe research institutions or other organisations involved in the scientific process, such as, museums, archaeological institutions, private collections, objects owners and so forth; HS_Department, for describing branches, sections or any other specific internal subdivision/organisation of research institutions or organisations; HS_Person, for single physical people playing a specific role in the research process.

The diagram below shows the hierarchy of actors and the properties with which they are linked to the research activities in CRMhs. Double arrows indicate IsA relations between classes. Properties are shown as single arrows.

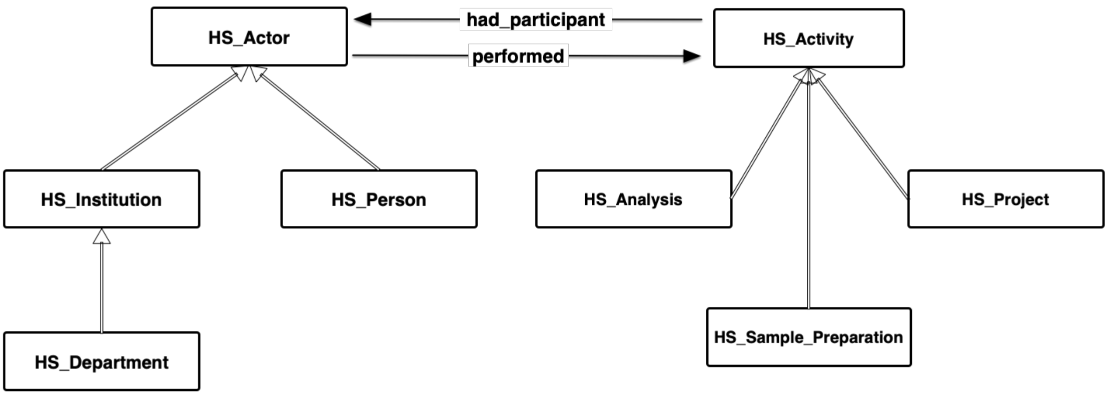

Figure 7: Activities and actors in CRMhs

It is interesting to note that the two main relationships between HS_Actor and HS_Activity (participation and direct performance) are inherited by all their subclasses, so that CRMhs offer the possibility to state using the same properties, for example, that an HS_Person performed an HS_Analysis or that an HS_Project had_participant an HS_Department.

Other typical properties are those used to indicate the belonging of persons (has_member) or sections (has_department) to specific institutions and those used to specifically identify the actors, (has_name, has_email).

5.3.4 Modelling times and places

Temporal Values

To assign temporal values to scientific activities, CRMhs provides two specific properties: has_start_date, has_end_date. The string (i.e. `xsd:string`) values for these properties can be expressed in different ways and with different levels of detail by using for example the XML standard notation, e.g. the `xsd:date` data type to indicate just the day in which an activity started, ended or took place (in the form YYYY-MM-DD), or the `xsd:dateTime` notation type (in the form CCYY-MM-DDThh:mm:ss.sss) for maximum precision up to the seconds.

Places and Place Identification

HS_Place is the CRMhs class used to describe the different places relevant to Heritage Science, such as those where an artwork is kept or exhibited, an archaeological artefact was produced or found, a sample was prepared and an experiment conducted, an institution resides. Instances of this class can be identified in various ways, according to the formats and vocabularies chosen by the institutions to represent places and express geographic data. CRMhs offers two mechanisms for expressing geographic entities:

1. The has_identifier property: for values from gazetteer and other geographic vocabularies where places are identified by IRIs or similar unique strings. For example, the https://www.geonames.org/3176959/ IRI used to identify the city of Florence (Italy) in the Geoname gazetteer, or the http://vocab.getty.edu/tgn/7011798 IRI used to identify the City of London (UK) in the Getty Thesaurus of Geographic Names (TGN).
2. The has_coordinates property, through which it is possible to express geographic coordinates of points, lines, polygons and so on in different formats. CRMhs does not enforce or recommend any specific geographic system or format as values for this property. It merely provides the possibility to specify coordinates in any type of geographic system that can be expressed as a string, for instance:
    - Using `lat,long` information (e.g. “43.77925, 11.24626”) to identify a point.
    - Using GML code, e.g.:

      ```
      <gml:Point gml:id="p1" srsName="WGS84">
          <gml:coordinates>
      43.77925, 11.24626
      </gml:coordinates>
      </gml:Point>
      ```
    - Using Well Known Text (e.g. “`POLYGON ((30 10, 40 40, 20 40, 10 20, 30 10))`”)

Portions of objects and their location

In Heritage Science it is typical that portions of objects located within specific areas their surface are investigated rather than the objects in their entirety. In addition to the

HS_Study_Object_Portion class, CRMhs also provides the HS_Study_Object_Area class, subclass of HS_Place, to indicate the surface of the study object within which the portion of object where the analysis took place is located. The special "occupies" property is used to express this relationship, as shown in Figure 8:

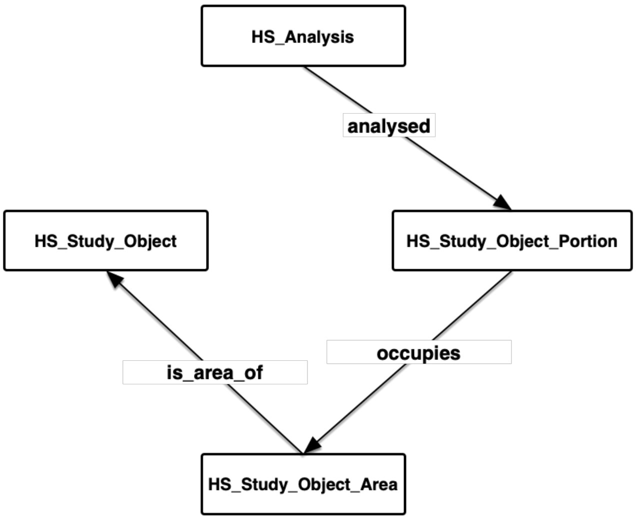

Figure 8: Object portions and their location within an object's surface

Research protocols

Analyses and sample preparation operations are often composed of a series of precisely defined procedures, often performed according to an already established standard protocol. It may be of particular importance to document this set of events as a process repeatable even several times and by different institutions. For this reason, the HS_Protocol class is provided.

6. Case Study 2: Bio-archaeology and Ancient DNA

During the first half of the project, FORTH-IMBB in close collaboration with FORTH-ICS worked on the definition of a model that would describe the ancient DNA wetlab services. We analyzed projects currently running in the aDNA laboratory facilities of FORTH-IMBB. Each project is initially described as an AO_Collection since it is an aggregation of resources. For the description of the AO_Collections FastCat was used. The properties of AO_Collection were found sufficient to describe aDNA projects at a high abstraction level. Then in order to describe in more detail the aDNA wetlab services we used classes and properties from CIDOC-CRM and the family of its compatible models:

- CIDOC CRM – The base model, version 6.2.1
- CRMsci – Scientific observation model, version 1.2.2
- CRMdig – Model for provenance metadata, version 3.2
- CRMarchaeo – Excavation model, version 1.4.1
- CRMpe – Model for Research Infrastructure management, the PARTHENOS Entity Model version 3.1.2

In the following sections we present a tentative modelling approach in detail. To make the modelling better understood we follow a specific use case of a Project on molecular sex and genetic diseases determination.

6.1 Brief use case description

Pilot scientific application of ancient DNA analyses (Molecular sex determination / Genetic diseases) and training of new scientists in the methodology of analysing excavated biological remains

- TIME PERIOD: Hellenistic Period (479-30 BC)
- PLACE: Ipeiros, Ancient Amvrakia, Western Necropolis - Western retaining wall of cemetery road
- EPHORATE: Ephorate of Antiquities of Arta - Principal Investigator: Varvara Papadopoulou
- FINDINGS: human bones. Genetic material has been recovered from archaeological skeletal material under consideration.
- Samples: skeletal (temporal bone fragment), dental (premolar, molar, bicuspid) in the aDNA lab for analysis.

Research goals

- investigate molecular sex determination using the aDNA methodological approach.
- investigate genetic diseases e.g. genetic anemias (sickle cell and thalassemia) and pathogens that cause malarias (often endemic in marshy and wetland environments). aDNA analysis regarding diseases from ancient remains is an interesting approach to the study of health and disease in past human populations.
- Training of new scientists in the methodology of analysing excavated biological remains.

The scientific analysis workflow is based on the protocol described by Allentoft et al. Nature vol. 522, p. 167–172 (2015) and has the following steps:

- Sampling
- DNA extraction & Library construction for aDNA (For ILLUMINA)
  - Step 1: DRILLING OF TEETH OR PETROUS BONE
  - Step 2: DNA EXTRACTION
  - Step 3: PREPARE ADAPTERS, BUILD LIBRARY
  - Step 4: QPCR QUANTIFICATION
  - Step 5: INDEXING PCR
- Sequencing and bioinformatics analyses
- Interpretation of the results and conclusions
- Publication of results

6.2 Information about the sample that will be used for DNA Extraction

Ancient DNA can be successfully recovered from a wide range of bioarcheological materials, including bone, teeth, desiccated and mummified soft tissues, palaeo-faeces, hair, dental calculus, seeds and other plant material, cultural objects, and sediments, among others. Efficient protocols for recovering ultrashort DNA fragments from archaeological sources have been developed.

As already mentioned, activities take place in the context of a project that has responsible actors and a description about its goals. The use of a controlled vocabulary to classify the projects could be very helpful. Project is modelled as an PE35_Project and supports a number of different activities. A core activity is the acquisition of the samples that are going to be used in the experiments. An acquisition activity (E8_Acquisition) consists of one or more sample taking activities (S2_Sample_Taking) that deal with each distinct sample. For each sample we record basic information about the archaeological excavation that the sample was found in. The sample itself is modelled as an S13_Sample and also, in the case of aDNA, as an E20_Biological_Object.

The archaeological excavation is modelled as an A9_Archaelogical_Excavation class. According to the scope note of A9_Archaelogical_Excavation:

> "This class describes the general concept of archaeological excavation intended as a coordinated set of activities performed on an area considered as part of a broader topographical, rural, urban, or monumental context. An archaeological excavation is usually under the responsibility of a coordinator, officially designated, which is legally and scientifically responsible for all the activities carried out within each of the excavation process units and is also responsible for the documentation of the whole process."

We thus model basic information about the archaeological excavation including the responsible ephorate, the broad location where it took place, the time period which it refers to, and the findings of interest from where the sample(s) are taken.

Figure 9 presents the sample information modelling.

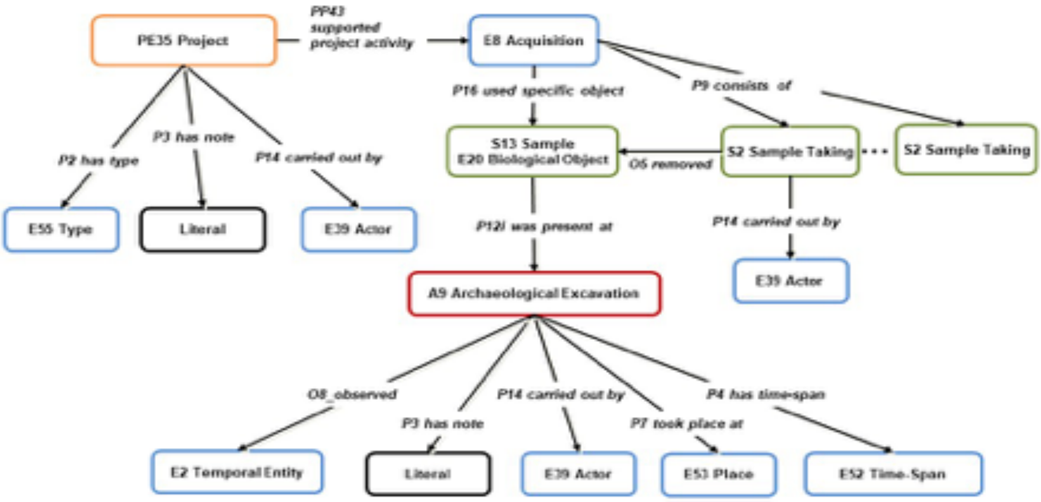

Figure 9: Sample information

The original sample is being processed in the lab before the actual experiments start. The processed sample is also modelled as an S13_Sample. In Figure 2 we can see the S2_Sample_Taking activity which O3_sampled_from the original S13_Sample and O5_removed the new S13_Sample.

Example: In our use case, two samples were taken. The first is a skeletal – temporal bone fragment while the second is a dental premolar. Only the first sample, the temporal bone, underwent an initial processing in order to get the desired targeting tissue which in this case was the petrous bone. According to our modelling we will have three S13_Sample instances, two for the initial samples and one for the resulting processed sample.

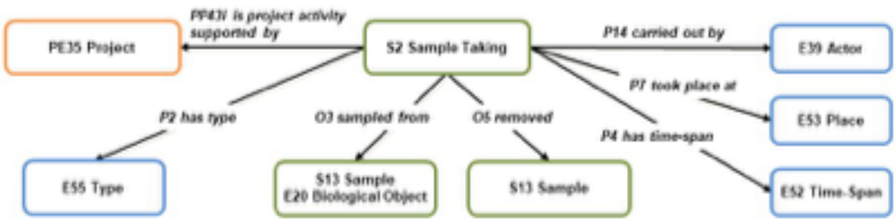

Figure 10: Sample processing

6.3 High-throughput sequencing library construction

Library refers to the end product of a suite of synthetic modifications made to the DNA in order to make it "readable" by sequencing instruments. Optimized for ancient DNA library construction protocols have been developed including robust protocols for both double-stranded and single-stranded DNA libraries, as well as the use of single- or dual-indexing to perform parallel sequencing of multiple samples in the same run. Quick and easy, double-stranded library preps are suitable for most archaeological samples with average to good preservation, whereas single-stranded library preps are used to recover DNA from marginal samples from warm climates or deep time.

Having acquired the appropriate samples there are a number of steps that are followed in a particular protocol (steps 2-5 in our use case). We modelled each step as an S4_Observation (Figure 3) which according to its scope note in CRMsci is:

> "… the activity of gaining scientific knowledge about particular states of physical reality through empirical evidence, experiments and measurements."

As with all activities we associate basic information with each S4_Observation regarding the person who did the processing, the place where it happened, the date, the protocol on which it is based, input parameters and of course the results (Figure 11).

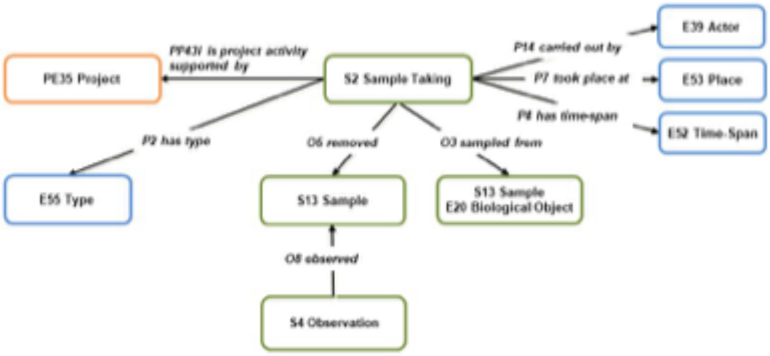

Figure 11: Modelling steps of a protocol

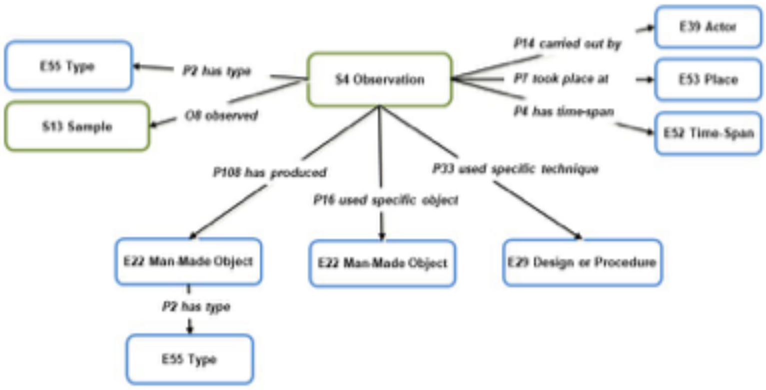

Figure 12: Basic step information

6.4 Sequencing

Sequencing is yet another S4_Observation which takes the output of the previous steps and performs the sequencing. The library that has been produced in the previous steps (E22_Man-Made_Object) is the input in the final sequencing activity (through the P16_used_specific_object property) as shown in Figure 12.

6.5 Alignment with CRMhs

The aDNA modelling started in parallel with the development of CRMhs. We plan a full alignment with CRMhs in order to have a complete framework for the description of all the data related to scientific activities in ARIADNEplus. A very first harmonization attempt of the Sample information is shown in Figure 13 and was done without encountering any alignment problems and/or incompatibilities.

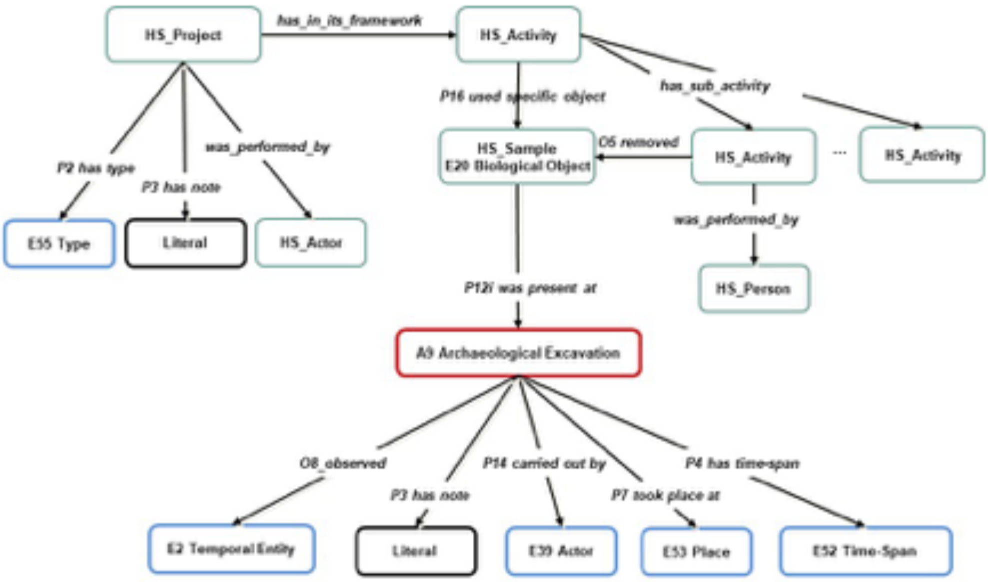

Figure 13: Alignment with CRMhs

7. Case Study 3: Inscriptions

Inscriptions are complex objects, characterised by the fact that they form a whole with their physical support. This close cohesion between the support and the text is, for instance, what distinguishes an inscription from a papyrus, the study of which mainly concerns textual analysis. The meaning of an inscription, instead, cannot be fully understood without the analysis of the object or monument or other archaeological objects on which it appears, just as one cannot fully understand the nature of that particular archaeological object without thoroughly investigating the sense of the inscription or iconographic representation it hosts.

Thus, any inscription is, from a conceptual point of view, an element with physical characteristics that are themselves bearers of meaning and of valuable information going far beyond the inherent meaning of the text. For instance, the shape of the letters, their spacing, the writing direction, technique and other similar characteristics provide precious clues to the times, makers and functions of the inscription itself. But also, the shape, the materials, the production techniques and all the attributes of the physical object that hosts the epigraph can become fundamental not only for their understanding but also for the definition of their nature.

Concerning the carriers, it should be noted that very often the physical supports have been designed and built specifically to accommodate an inscription, even if certain inscriptions may in fact have been placed on objects not specifically designed to accommodate them, as in the case of buildings, vessels or other objects of daily use on which an inscription may have been placed at a later time. There are also cases in which the inscription is placed on natural surfaces not created by human activities, such as inscriptions on rocks, in caves or other similar natural places.

From a conceptual point of view an inscription can be analysed according to three main aspects: the text-bearing object or monument, obviously involving archaeological topics, the text and its obvious correlations with content and linguistic aspects, and the feature engraved on the support in the form of letters or other symbols, which is the central element that characterizes and differentiates an inscription from any other manifestation of written communication.

In terms of integration and interoperability it is important to note that, thanks to its nature, the physical support constitutes one of the main points of contact between epigraphy and archaeology. The specific archaeological aspects (discovery, provenance, archaeological context etc.) relating to the physical support can be documented using AO-Cat and the CRMarchaeo extensions of CIDOC CRM.

Concerning the investigation and study of inscriptions, one of the most important operations carried out by epigraphists for their study, and especially for publication, is the so-called “reading” of the inscription, consisting of a deep and accurate analysis and study of the surface and the signs followed by establishing as faithful as possible what is shown by the physical feature.

The graphemes (i.e. letters or syllables) inferred from the observation of an inscription represent the level of the intellectual decoding and understanding of the signs and constitute the basis for the subsequent operations of transcription usually carried out by epigraphists, in particular for the so-called diplomatic transcription (i.e., a specific transcription recording only the characters as they appear on the support, without any editorial intervention or interpretation), which is also of great importance from the point of view of publication. The publishers of an epigraph, for practical reasons, generally those of typeface, perform these transcriptions using Latin or Greek characters, even in case of non-Latin and non-Greek inscriptions (Etruscan inscriptions, for example).

Based on these requirements and conceptual considerations, a first draft of the application profile for the inscriptions was defined during the first half of the project. Below, some procedures used for its definition and some specific features offered by this preliminary version of the model are presented.

7.1 Existing models for ancient texts description

Two existing models, developed specifically for the description of ancient texts in various contexts, were chosen as the basis for the construction of the application profile and the modelling of the various features listed above for inscriptions.

The first one is CRMtex[8], an ontological model based on CIDOC CRM created to describe ancient texts and other semiotic features appearing on inscriptions, papyri, manuscripts and other media. The model is also designed to describe in a formal way the phenomena related to the production, use, conservation, study and interpretation of textual entities. The second one is EPNet[9], a CIDOC CRM based ontology designed to deal with inscriptions, events and objects connected with the distribution of food in the Roman world. The full compatibility of these models with the AO-Cat, CIDOC CRM ontology and its extensions ensures persistent interoperability of data encoded by means of their entities.

7.2 A tentative workflow for ARIADNEplus

In the perspective of ARIADNEplus, below we describe some of the main entities needed to describe the inscriptions and their characteristics.

Typically, inscriptions, stamps and graffiti are physical features found on portable objects, such as coins, vases, weapons, jewels and other similar portable objects that usually come from archaeological contexts, museums or collections. They can also be found on architectural objects (for example, monuments, buildings or parts of them) or in natural contexts such as rocks, caves and caverns. The function of inscriptions and graffiti is usually to record the memory of an event, transmit or convey public messages, mark a territory, publish laws and edicts, and provide testimony of past events. Stamps and trademarks have the main function of identifying objects or their content, their functions, their owners or the factories or shops in which they were produced.

[8] Full documentation available at http://www.cidoc-crm.org/crmtex/

[9] More information at http://romanopendata.eu/sparql/doc/index.html

From a conceptual point of view, inscriptions, stamps, graffiti can be represented, in their physical manifestations, by classes declared as equivalent or subclasses of the TX1 Written Text (CRMtex) or EP:Graffito, EP:TitulusPictus, EP:Stamp of the EPNet model. The human made objects and surfaces and the natural surfaces such as rocks and caves, carrying the textual or iconographic features, can be modeled by means of the AO_Object class of AO_Cat. The text, in its conceptual and semantic dimension, can be represented with classes derived from the E33 Linguistic Object, the E90 Symbolic Object of CIDOC CRM and the F22 Expression of FRBRoo. The special relationship that binds texts and graphic symbols to their support can be expressed by means of specific properties, inspired e.g. by the P128 carries of CIDOC CRM or the EP:carries of EPNet. Figure 14 exemplifies a possible modelling of these entities.

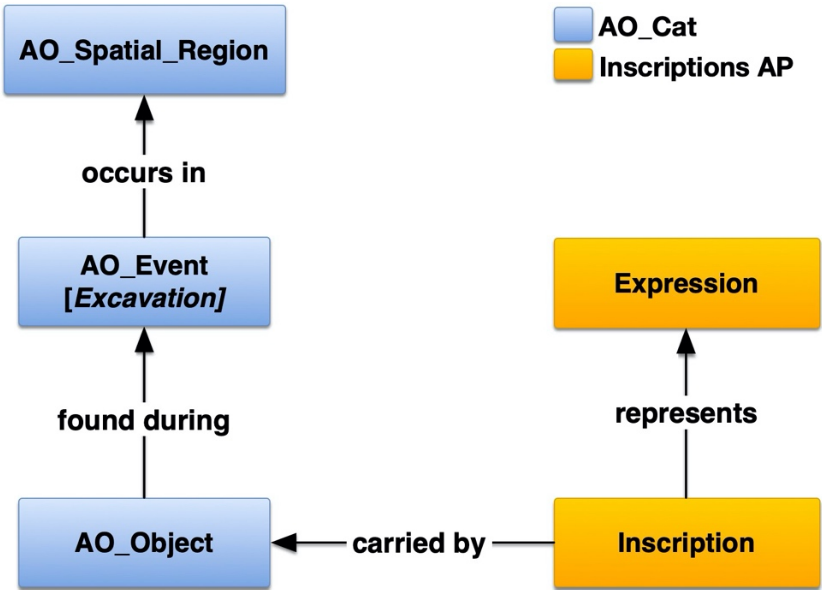

Figure 14: Physical and conceptual manifestation of an inscription and its carrier

7.3 Study and investigation activities

The study of ancient textual documents typically starts from the analysis of the physical characteristics of the text itself before moving to their archaeological, palaeographic, linguistic and historical characteristics. The scratching or engravings on an inscription or a graffiti are fundamental elements for the study not only of the text but also of the archaeological objects on which the text appears. The text of an inscription, for instance, can be cancelled by chiselling or otherwise obliterated and destroyed to make way for a new text or simply to represent a form of *damnatio memoriae*. This and other similar phenomena are of fundamental importance for the reconstruction of the history of the object

Of equal importance is the study of the text as a linguistic phenomenon together with the study of any iconographic apparatus that accompanies it. The production of the physical manifestations of a text is in fact inextricably linked to the intellectual activity of the encoding of a linguistic expression through a specific activity called “writing”. Peculiar elements such as the language, the graphic system or the iconographic apparatus from which the signs and letters used to make the inscription are derived, assume particular importance in this context.

In this perspective, the past event of creation of an inscription can be easily described by means of class equivalent to TX Writing of CRMtex, to which it is possible to associate a writing system in a similar way in which CRMtex does by means of the TX3 Writing System class and the TXP1 used writing system property. The writing event allows the assignment of a production date directly to the inscription (for instance by means of the EP:hasProductionDate property of EPNet or P2_has_time_span of CIDOC CRM) in order to distinguish it from that of the physical support that hosts the inscription, which in many cases can have a different (usually earlier) production date. Figure 15 illustrates how these classes and properties interact.

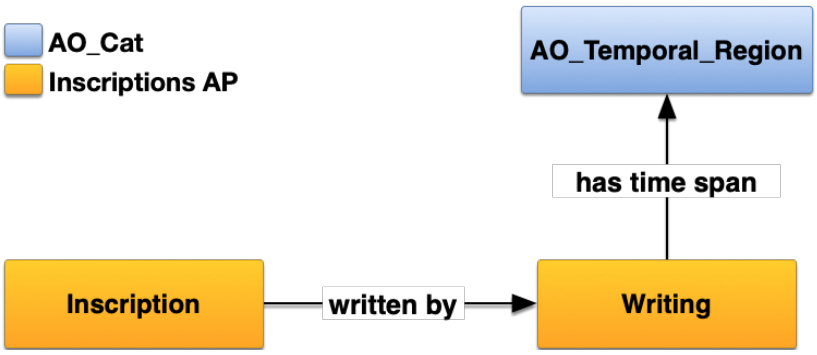

Figure 15: Writing of an inscription and temporal region within which this event falls

The activities of reading and decoding of a text and the deciphering of the iconographic signs are particularly sophisticated scientific observations that consist in the accurate autoptic examination of the surface and the physical signs and prescribe the use of specific tools and procedures to establishing as faithfully as possible the exact value of each sign drawn on the physical feature. The intellectual decoding and understanding of the text signs (graphemes) form the basis for the correct reading of the text and the right decoding and interpretation of the other symbolic and artistic signs used for complementing and decorating it, as clarified in the scope notes of the TX5 Reading class of CRMtex from which it is possible to take direct inspiration.

The final goal in the study of inscriptions or graffiti is the publication of their critical editions, which usually involves the transcription of the texts, the integration, if required, of missing letters or words, the reproduction of the various accompanying symbols and drawings and the formulation of possible translations and interpretations of them, to be used by other scholars. Classes equivalent to the TX6 Transcription of CRMtex and EP:isTranscribedBy of EPNet can be easily defined to model these documentation techniques to be incorporated into the investigation documentation and publication.

If the produced documentation is in digital format, a set of datasets (described in AO_Cat by means of the AO_Digital_Resource class of AO_Cat) are produced as results of the investigation activities, archived and made available to be examined by other scholars for analyses, hypothesis formulation and interpretations, in order acquire new data for integrating their studies. This process of investigation of an inscription and the consequent creation of a dataset containing its description is illustrated in Figure 16.

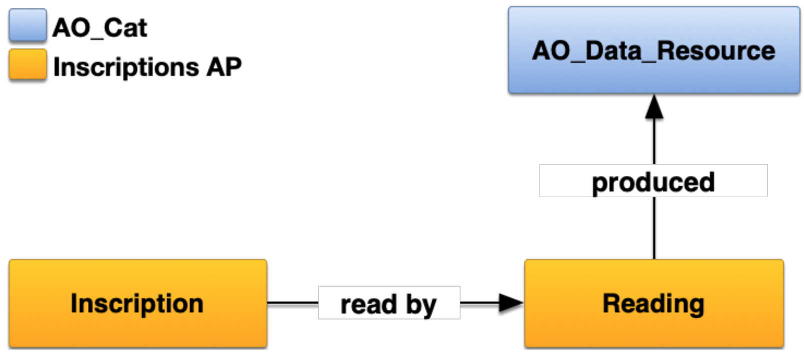

Figure 16: The process of investigation (reading) of an inscription and production of the related (digital) documentation

The specific classes and properties of the application profile for the inscriptions described above will allow, once defined in a formal way, to model the most relevant phenomena of this type of data by providing a direct relationship with the digital resources relating to inscriptions, graffiti and stamps (e.g. by means of the is_about property) catalogued in ARIADNEplus, and to consistently document their spatial coverage and temporal projection as shown in Figure 17.

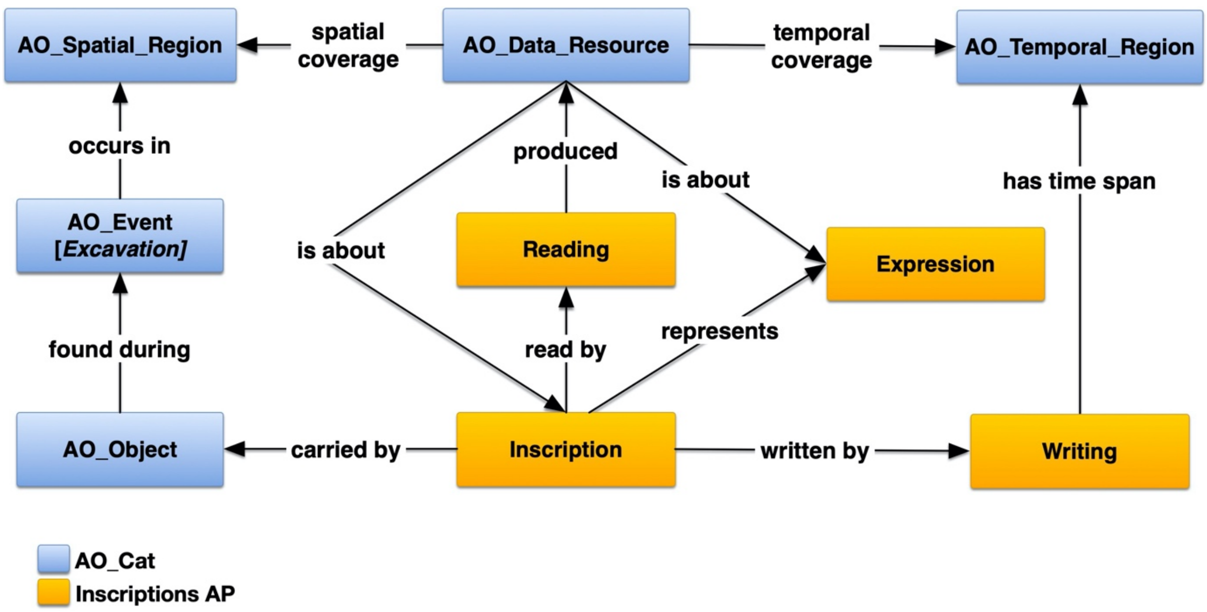

Figure 17: Overview of the interactions between the main classes of the application profile for inscriptions and the AO-Cat model

8. Towards the ARIADNE Ontology

As it has been noted in Section 3, the AO-Cat ontology and the application profiles are developed as refinements of the CIDOC CRM, which has been assumed as the conceptual backbone of AO. Technically, this means that the classes and the properties of AO-Cat and the application profiles are mapped to the CIDOC CRM. As a consequence, the AO-Cat and the application profiles are integrated with one another *by design* through the CIDOC CRM: the union of those ontologies with the CIDOC CRM yields a single, harmonized ontology.

That ontology, generally referred as “the ARIADNE Ontology” (AO for short), provides the linguistic and axiomatic basis of the ARIADNE Content Cloud (AC for short) and, together with the adoption of the semantic web sets of standards, gives the best possible effort for the interoperability of the AC with the Linked Data datasets in the Cultural Heritage domain.

One of the most relevant models for the definition and the harmonisation of the ARIADNEplus application profiles, and the context for the definition of the ARIADNE Ontology, is CRMarchaeo[10], the extension of CIDOC CRM created to support the archaeological excavation process and all the related entities and activities. CRMarchaeo was developed by an international community of archaeologists coming from various cultural heritage institutions and with the contribution of ARIADNE (Doerr et al. 2016) with the purpose of providing all necessary tools to manage and integrate existing documentation in order to formalise knowledge derived from observations during the archaeological activity. Its purpose is to facilitate the semantic encoding, exchange of and access to existing archaeological documentation and the establishment of interoperability among them.

CRMarchaeo is able to model and relate the physical arrangement of archaeological stratification and the events that led to their formation. It also enables the description of the nature and shape of existing stratifications and surfaces and the analysis of the human remains or artefacts found within the investigated strata. Its final goal is to document the interpretation of the stratigraphic sequences and their chronological arrangement, according to the space-time analysis of the investigated sites, in order to make inferences on the life, beliefs, behaviour and activities of groups of people who occupied those areas in the past.

Another key point of the model is the ability to overcome the differences resulting from the application of different excavation techniques and procedures established by different archaeological traditions and schools, revealing the common ways of thinking that characterise stratigraphic excavation. This will serve to provide a unified view that can express common concepts without imposing any specific recording or modelling technique on documentation of stratigraphic activity and will also provide a solid basis for the integration of datasets resulting from various investigation methodologies.

For these reasons, CRMarchaeo constitutes one of the fundamental models for documenting many aspects of the various sub-disciplines of Task 4.4 which, being mainly focused on archaeology, almost always have archaeological entities or activities referenced in their study. For example: scientific

[10] http://www.cidoc-crm.org/crmarchaeo/

analyses are often carried out on objects coming from archaeological contexts; the physical supports on which inscriptions are found are in most cases archaeological objects; coins and other human-made artefacts are typically found during archaeological excavations, surveys and other similar activities, and so on. For this reason, many of the application profiles that we are defining in ARIADNEplus rely on CRMarchaeo as well as on CIDOC CRM to ensure coherence and stability to the data aggregated at item-level.

The next priorities for WP4 are to complete work on those application profiles that are already well advanced, to assess which sub-domains which are underway can be amalgamated and harmonised and to complete the outstanding profiles, where possible, taking account of the existing CIDOC CRM extensions. Workshops are also planned to investigate how the application profiles can be implemented within VREs to be developed in D4Science, and how these will help address the research questions of archaeologists by allowing them to combine multiple datasets.

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Appendix: classes and properties of the CRMhs model

General overview

CRMhs is an application ontology developed to capture and represent all the elements of the scientific activity related to Heritage Science. The ontology results from the harmonization of different existing ontologies that already excel in modelling general aspects related to research activities, and provides new entities specifically designed for Heritage Science in order to represent the peculiar aspects of this domain. It is also based on the inputs received from several activities carried out in the ARIADNEplus project and centered around description of scientific activities and data.

The CRMhs model is composed of a set of independent classes used for distinguishing and defining each of the entities involved in a specific scientific analysis, and of a set of relationships used for linking these entities between each other, according to the specific sequences of events in which they are involved. All classes and properties are built on the basis of international standards of primary importance in the field of Cultural Heritage and Heritage Science. As a conceptual backbone, the CIDOC CRM ontology has been adopted; thus, each class and property in CRMhs is accompanied by specific mappings to CIDOC CRM and its extensions that guarantee compatibility and semantic interoperability. The encoding of the data in CRMhs, therefore, allows their immediate compatibility with the CIDOC CRM and the ARIADNEplus ecosystem.

The table below shows all the existing ontologies used for the definition of CRMhs. Details about the mappings are provided within the description of each class and property of the model.

Ontologies used for CRMhs harmonisation

CIDOC CRM	A formal ontology intended to facilitate the integration, mediation and interchange of heterogeneous cultural heritage information
CRMsci	The scientific observation model
CRMdig	Model for provenance metadata
CRMpe	The PARTHENOS Entities model
AO-Cat	ARIADNE Ontology - Resource Catalog Model

Hierarchy of CRMhs Classes

The schema below presents the complete hierarchy of all the CRMhs classes and subclasses.

HS_Entity

- **HS_Type**
- **HS_Activity**
  - **HS_Project**
  - **HS_Analysis**

    - **HS_Sample_Preparation**
- **HS_Object**
    - **HS_Study_Object**
        - **HS_Study_Object_Portion**
        - **HS_Sample**
    - **HS_Device**
        - **HS_Device_Component**
    - **HS_Software**
    - **HS_Dataset**
- **HS_Actor**
    - **HS_Institution**
        - **HS_Department**
    - **HS_Person**
- **HS_Place**
    - **HS_Study_Object_Area**
- **HS_Period**
- **HS_Protocol**

Domain and Range of CRMhs Properties

The following table presents all CRMhs properties providing domain and range for each of them.

Property	**Domain**	**Range**
has_identifier	HS_Entity	xsd:string / rdfs:Resource
has_type	HS_Entity	HS_Type
has_name	HS_Entity	xsd:string
has_description	HS_Entity	xsd:string
has_uri	HS_Entity	xsd:string
has_label	HS_Entity	xsd:string
was_performed_on	HS_Activity	HS_Object
in_the_framework_of	HS_Activity	HS_Project
used_method	HS_Activity	xsd:string / rdfs:Resource
has_sub_activity	HS_Activity	HS_Activity
was_performed_by	HS_Activity	HS_Actor
had_participant	HS_Activity	HS_Actor
was_performed_at	HS_Activity	HS_Place

Property	**Domain**	**Range**
was_performed_during	HS_Activity	HS_Period
has_start_date	HS_Period	xsd:dateTime
has_end_date	HS_Period	xsd:dateTime
was_funded_by	HS_Project	HS_Actor
analysed	HS_Analysis	HS_Study_Object
used_protocol	HS_Analysis	HS_Protocol
used_device	HS_Analysis	HS_Device
used_component	HS_Analysis	HS_Device_Component
used_software	HS_Analysis	HS_Software
produced_dataset	HS_Analysis	HS_Dataset
prepared	HS_Sample_Preparation	HS_Sample
has_coordinates	HS_Place	xsd:string
is_made_of	HS_Study_Object	xsd:string
was_created_by	HS_Study_Object	HS_Actor
has_period	HS_Study_Object	HS_Period
has_location	HS_Study_Object	HS_Place
was_found_at	HS_Study_Object	HS_Place
was_found_by	HS_Study_Object	HS_Actor
is_part_of	HS_Study_Object	HS_Study_Object
belongs_to	HS_Study_Object	xsd:string / rdf:Resource
has_owner	HS_Study_Object	HS_Actor
has_area	HS_Study_Object	HS_Study_Object_Area
occupies	HS_Study_Object_Portion	HS_Study_Object_Area
was_taken_from	HS_Sample	HS_Object
has_maker	HS_Device	HS_Actor

Property	Domain	Range
has_residence	HS_Actor	HS_Place
has_department	HS_Institution	HS_Department
has_member	HS_Institution	HS_Person
has_email	HS_Actor	xsd:string
has_format	HS_Dataset	xsd:string
has_language	HS_Dataset	xsd:string
created_using_software	HS_Dataset	HS_Software
used_by_software	HS_Dataset	HS_Software
used_by_service	HS_Dataset	xsd:string / rdf:Resource
is_accessible_at	HS_Dataset	xsd:string / rdf:Resource

CRMhs Classes Mappings

The following table provides a description of mappings for each CRMhs class. Mappings are provided both with respect to CIDOC CRM, to foster interoperability with other archives based on this ontology and the extensions of its ecosystem, and to AO_Cat, in order to automate the generation of metadata for the ARIADNEplus catalogue.

CRMhs Class	CRM Family Mapping	AO-Cat Mapping
HS_Entity	Subclass of E1 CRM Entity (CRM)	AO_Entity
HS_Type	Equivalent to E55 Type (CRM)	AO_Concept
HS_Activity	Subclass of E7 Activity (CRM)	AO_Activity
HS_Object	Subclass of E70 Thing (CRM)	AO_Object
HS_Actor	Equivalent to E39 Actor (CRM)	AO_Agent
HS_Place	Equivalent to E53 Place (CRM)	AO_Spatial_Region
HS_Period	Equivalent to E4 Period (CRM)	AO_Temporal_Region
HS_Project	Equivalent to PE35 Project (CRMpe)	AO_Activity
HS_Analysis	Equivalent to S4 Observation (CRMsci)	AO_Activity
HS_Sample_Preparation	Subclass of E7 Activity (CRM)	AO_Activity

CRMhs Class	CRM Family Mapping	AO-Cat Mapping
HS_Protocol	Subclass of E29 Design or Procedure (CRM)	
HS_Study_Object	Subclass of E18 Physical Thing (CRM)	AO_Object
HS_Study_Object_Portion	Subclass of E24 Physical Human-Made Thing (CRM)	AO_Object
HS_Sample	Equivalent to S13 Sample (CRMsci)	AO_Object
HS_Study_Object_Area	Subclass of E53 Place (CRM)	AO_Object
HS_Device	Equivalent to D8 Digital Device (CRMdig)	
HS_Software	Equivalent to D14 Software (CRMdig)	
HS_Device_Component	Subclass of E18 Physical Thing (CRM)	
HS_Dataset	Equivalent to PE18 Dataset (CRMpe)	AO_Data_Resource
HS_Institution	Equivalent to E74 Group (CRM)	AO_Group
HS_Department	Subclass of E74 Group (CRM)	AO_Group
HS_Person	Equivalent of E21 Person (CRM)	AO_Person

CRMhs and CIDOC CRM Properties Mapping

The following table provides a description of mappings for each CRMhs property to CIDOC CRM, to foster interoperability with other archives based on this ontology and the extensions of its ecosystem.

CRMhs Property	CRM Family Mapping
has_identifier	E1 CRM Entity → P1 is identified by → E42 Identifier
has_type	P2 has type
has_name	E1 CRM Entity → P1 is identified by → E41 Appellation
has_description	P3 has note
has_uri	E1 CRM Entity → P1 is identified by → E41 Appellation → E55 has type = “URL”
has_label	E1 CRM Entity → P1 is identified by → E41 Appellation → E55 has type “LABEL” | skos:prefLabel

CRMhs Property	CRM Family Mapping
was_performed_on	P12 occurred in the presence of
in_the_framework_of	PP43i is project activity supported by
analysed	O8 observed
has_sub_activity	P9 consists of
was_performed_by	P14 carried out by
had_participant	P11 had participant
was_performed_at	P7 took place at
has_start_date	E2 Temporal Entity → P4 has time-span → E52 Time Span → P79 beginning is qualified by → E63 String
has_end_date	E2 Temporal Entity → P4 has time-span → E52 Time Span → P80 end is qualified by of → E62 String
was_funded_by	PE35 Project → PP56 was award of → PE42 Funding Activity → PP54 had awardee → E39 Actor
used_protocol	P33 used specific technique
used_device	P16 used specific object
used_component	P16 used specific object
used_software	P16 used specific object
produced_dataset	S4 Observation → P9 consists of → D7 Digital Machine Event → L11 had output → PE18 Dataset
prepared	E7 Activity → P12 occurred in the presence of → E77 Persistent Item
has_coordinates	P168 place is defined by
is_made_of	P45 consists of
was_created_by	E24 Physical Human-Made Thing → P108 was produced by → E12 Production → P14 carried out by → E39 Actor
has_period	E18 Physical Thing → P92 was brought to existence by → E63 Beginning of Existence → P10 falls within → E4 Period
has_location	P55 has current location
was_found_at	E18 Physical Thing → O19 was object found by → S19 Encounter Event → O21 has found at → E53 Place

CRMhs Property	CRM Family Mapping
was_found_by	E18 Physical Thing → O19 was object found by → S19 Encounter Event → P14 carried out by → E39 Actor
is_part_of	P46 forms part of
belongs_to	P46 forms part of
has_owner	P52 has current owner
has_area	P59 has section
occupies	P156 occupies
was_taken_from	S13 Sample → O5 was removed by → S2 Sample Taking → O3 Sampled From→ S10 Material Substantial
has_maker	L33 has maker
has_residence	P74 has current or former residence
has_department	P107 has current or former member
has_member	P107 has current or former member
has_email	E39 Actor → P1 is identified by → E41 Appellation → E55 has type "email"
has_format	P2 has type
has_language	PE18 Dataset → P165 incorporates → E33 Linguistic Object → P72 has language → E56 Language
created_using_software	PE18 Dataset → P94i was created by → D10 Software Execution → P16 used specific object → D14 Software
used_by_software	PE18 Dataset → P19i was made for → D10 Software Execution → L23 used software or firmware → D14 Software
used_by_service	
is_accessible_at	PE18 Dataset → PP50 is accessible at → PE29 Access Point

AO_Cat Properties and CRMhs Mapping

The following table provides a description of mappings for each AO_Cat property to CRMhs, in order to automate the generation of metadata for the ARIADNEplus catalogue.

AO_Cat Property	CRMhs Mapping/Path
has_identifier	has_identifier
has_type	has_type
has_title	has_name
has_description	has_description
was_issued	has_end_date
was_modified	has_end_date
has_part	
has_publisher	was_performed_by
has_contributor	had_participant
has_creator	was_performed_by
has_owner	was_performed_by
has_responsible	was_performed_by
has_original_id	HS_Dataset → has_identifier
refers_to	HS_Dataset → dataset_produced_by → HS_Analysis → was_performed_on → HS_Object
is_about	HS_Dataset → dataset_produced_by → HS_Analysis → was_performed_on → HS_Study_Object
has_ARIADNE_subject	HS_Study_Object → has_type → HS_Type → has_uri → AAT Concept (if available)
has_native_subject	HS_Study_Object → has_type
has_language	has_language
was_created_on	has_end_date
has_landing_page	is_accessible_at
has_temporal_coverage	has_period
occurs_in	was_performed_at
happens_at	has_start_date + has_end_date
contains_event	has_sub_activity

AO_Cat Property	CRMhs Mapping/Path
has_period	has_period → HS_Period → has_uri
has_native_period	has_period
has_spatial_coverage	has_location
has_time_interval	has_period
has_space_region	has_location
was_present_at	was_performed_on
has_name	HS_Actor → has_name
has_agent_identifier	HS_Actor → has_identifier
has_email	has_email
has_home_page	HS_Actor → has_uri
from	HS_Period → has_start_date
until	HS_Period → has_end_date
has_place_name	HS_Place → has_name
has_latitude	Derived from has_coordinates
has_longitude	Derived from has_coordinates
has_bounding_box_min_lat	Derived from has_coordinates
has_bounding_box_min_lon	Derived from has_coordinates
has_bounding_box_max_lat	Derived from has_coordinates
has_bounding_box_max_lon	Derived from has_coordinates
has_place_IRI	HS_Place → has_uri
has_polygonal_representation	Derived from has_coordinates
has_institution	HS_Person → is_member_of

CRMhs Classes

This section presents in detail all the classes and properties of the CRMhs model. A simple notation is used for description. In particular, class axioms are stated using a common template giving:

- the name of the class, given as the title of the section presenting the property; CRMhs classes are all named following a single schema: the string "HS_" is used as a prefix, followed by a name that indicates the type of resource rendered by the class. Thus, HS_Event names the class of events, HS_Object that of objects and so on. If the class name is formed with two or more words, they are separated by an underscore.
- the sub- and super-classes of the class are given for convenience.
- scope notes stating the informal semantics of the class.
- examples of resources that are instances of the class.
- the mapping to classes of CIDOC CRM, AO_Cat and other compatible models as specified in Table 1.
- the properties having the class as domain; the same information is given upon defining properties, but it is repeated here for convenience; properties inherited from super-classes are not repeated.

HS_Entity

Superclass of: HS_Activity, HS_Object, HS_Actor, HS_Place, HS_Protocol.

Scope note: HS_Entity is the root class of the model, it has no direct instances, but the instances of all the classes are also instances of this root class. All classes are subclasses of this one and general properties propagate to all the classes of the models.

Maps to: HS_Entity is a subclass of E1 CRM Entity of CIDOC CRM and is equivalent to AO_Entity of AO_Cat.

Domain of: has_identifier, has_type, has_name, has_description, has_uri, has_label.

HS_Type

Subclass of: HS_Entity.

Scope note: This class comprises terms in thesauri, controlled vocabularies or any other reference resource providing concepts in a domain of interest. HS_Type is also declared as equivalent to the skos:Concept class of the SKOS model.

Maps to: HS_Type is equivalent to E55 CRM Type of CIDOC CRM, skos:Concept in SKOS and AO_Concept in AO_CAT.

HS_Activity

Subclass of: HS_Entity.

Superclass of: HS_Project, HS_Analysis, HS_Sample_Preparation.

Scope note: This class comprises all the activities carried out in the scientific domain, aimed to coordinate, facilitate and foster analysis of specific objects and samples in order to acquire knowledge about them. Scientific activities include operations of resources acquisition, organisation and deployment (e.g., projects), preparation of objects and samples for analysis, scientific measurements by means of different techniques and tools, and any other specific activity performed within the scientific domain. Thus, HS_Activity is a general superclass for the HS_Project, HS_Analysis and the HS_Sample_Preparation classes of this model.

Maps to: HS_Activity is a subclass of E7 Activity of CIDOC CRM and is equivalent to AO_Activity of AO_Cat.

Domain of: was_performed_on, in_the_framework_of, used_method, has_sub_activity, was_performed_by, had_participant, was_performed_at, was_performed_during, has_start_date, has_end_date.

HS_Object

Subclass of: HS_Entity.

Superclass of: HS_Study_Object, HS_Dataset, HS_Device, HS_Software.

Scope note: This class comprises all the physical and digital objects or parts of them in the domain of scientific investigations, including the analysed objects (or portions of them), the samples, the devices used for the scientific measurements, the software and the datasets resulting from scientific investigations, that in turn can be further analysed for instance to interpret the results they contain or generate graphical representations out of them. Thus, HS_Object is a general superclass for the HS_Study_Object, HS_Study_Object_Portion, HS_Sample, HS_Device, HS_Dataset and HS_Software classes of this model.

Maps to: HS_Object is a subclass of E70 Thing of CIDOC CRM and of AO_Object of AO_Cat.

HS_Actor

Subclass of: HS_Entity.

Superclass of: HS_Institution, HS_Department, HS_Person.

Scope note: This class comprises actors (i.e. institutions and people) of different kinds involved in experimental analyses and in the creation of related documentation and datasets. HS_Actor is a general superclass designed to provide common properties for the HS_Institution, HS_Department and HS_Person classes of this model.

Maps to: HS_Actor is equivalent to E39 Actor of CIDOC CRM and to AO_Agent of AO_Cat

Domain of: has_residence, has_email.

HS_Place

Subclass of: HS_Entity.

Superclass of: HS_Study_Object_Area.

Scope note: This class is intended to provide information about the various places in which scientific activities have been carried out, such as for example the research laboratories where objects are brought to be analyzed, or the places where objects are usually placed (e.g. monuments or archaeological sites) or kept (museums or collections), in cases where the analyses take place directly there.

Examples: - The Florence labs of the Italian National Institute of Nuclear Physics (INFN).
- The labs of the restoration centre Opificio delle Pietre Dure in Florence.
- The Galleria Alberoni in Piacenza.

Maps to: HS_Place is equivalent to E53 Place of CIDOC CRM and AO_Spatial_Region of AO_Cat.
Domain of: has_coordinates

HS_Period

Subclass of: HS_Entity.
Scope note: This class is intended to provide information about the temporal spans and periods related to study objects. Instances of this class are intended to represent temporal entities in different shapes, e.g. as period names, period URIs and time intervals.
Examples: The Italian "Rinascimento" (http://n2t.net/ark:/99152/p0qhb66pk6z in PeriodO)
Maps to: HS_Period is equivalent to E4 Period of CIDOC CRM and AO_Temporal_Region of AO_Cat.

HS_Project

Subclass of: HS_Activity.
Scope note: This class comprises collaborative initiatives, undertaken over a period of time by groups of actors with the intention of performing a defined program entailing the support of a number of analysis and other scientific activities.
Examples: The ARIADNEplus Project.
Maps to: HS_Project is equivalent to PE35 Project of CRMpe and AO_Activity of AO_Cat.
Domain of: was_funded_by.

HS_Analysis

Subclass of: HS_Activity.
Scope note: This class comprises the specific activities consisting of scientific observations and measurements performed on objects or samples by means of specific instruments, at specific places (e.g., laboratories, museums) and during a given time. Analysis can be of different types, i.e. non-destructive, when performed using non-invasive techniques; or destructive, e.g. when carried out on samples whose analysis requires their destruction. Analyses can be also composed of a series of precisely defined procedures, often performed according to an already established standard protocol. It may be of particular importance to document this set of events as a process repeatable even several times and by different institutions.
Examples:
- The XRF analysis performed to determine the elemental composition of an ancient Greek vase.
- The Pb isotopic ratio measurements performed to determine the provenance of Roman lead coins.
- The Accelerator Mass Spectrometry measurements to date organic remains from an archaeological site.

Maps to: HS_Analysis is equivalent to S4 Observation of CRMsci and AO_Activity of AO_Cat.
Domain of: analysed, used_protocol, used_device, used_component, used_software, produced_dataset.

HS_Sample_Preparation

Subclass of: HS_Activity.

Scope note: This class comprises specific activities or sets of activities aimed at preparing samples for the analysis. The sample preparation actions can often be seen as sub-activities of the main analysis (such as in the case of C14). Sample preparation can result in the modification of the original sample or even the production of new samples on which the actual analysis takes place.

Examples: - Chemical procedures used to graphitize organic remains for AMS dating.
- Chemical and physical procedures used to extract luminescent crystals from pottery for Thermoluminescence dating.

Maps to: HS_Sample_Preparation is a subclass of E7 Activity of CIDOC CRM and AO_Activity of AO_Cat.

Domain of: prepared.

HS_Protocol

Subclass of: HS_Entity.

Scope note: This class comprises research protocols, i.e. the plannings defined by scholars for the proper performing of an experimental activity. A protocol should contain detailed description of the elements, methodologies, tools and procedures used to carry out a scientific analysis as well as the objectives intended to be pursued and the expected results.

Examples: - The "Fine Grain/Coarse Grain" protocols for sample preparation in Thermoluminescence dating.

Maps to: HS_Protocol is a subclass of E29 Design or Procedure of CIDOC CRM.

HS_Study_Object

Subclass of: HS_Object.

Superclass of: HS_Study_Object_Portion, HS_Sample.

Scope note: This class comprises physical objects or artefacts investigated by scientific analysis and including archaeological finds, human remains and other organic and inorganic materials; art works and artefacts like paintings, frescoes, statues, reliefs, architectural elements, etc. It is of particular importance to keep track of the origin and provenance of these objects and materials, the conditions under which they were removed from their original contexts, the methods employed for their preservation and preparation for analysis, in order to properly relate the results of the scientific investigations with their original contexts. Many study objects are often already equipped with metadata created by museums or other cultural institutions by which they have been held or they have been studied. Sometimes they already have CRM descriptions, inherited from other cultural heritage documentation and referable via unique identifiers.

Examples: - The François Vase of the Archaeological Museum of Florence.
- Roman lead coins.

- Human remains from an archaeological site.

Maps to: HS_Study Object is a subclass of E18 Physical Thing of CIDOC CRM and AO_Object of AO_Cat.

Notes: If the was_created_by property is instantiated, instances of the E24 Physical Human-Made Thing class can be created to specify that the Study Object is an artefact, art work or another similar human-made thing.

Domain of: is_made_of, was_created_by, has_period, has_location, was_found_at, was_found_by, is_part_of, belongs_to, has_owner, has_area.

HS_Study_Object_Portion

Subclass of: HS_Study_Object.

Scope note: This class comprises portions or sections of artefacts or other physical objects selected to be investigated by a scientific analysis. Portions and sections can be associated to geometric areas of the objects or samples and identified by specific coordinates.

Examples: The rectangular portion of the François Vase of the Archaeological Museum of Florence investigated by XRF analysis.

Maps to: HS_Study_Object_Portion is a subclass of E24 E18 Physical Thing of CIDOC CRM and AO_Object of AO_Cat.

Domain of: occupies.

HS_Sample

Subclass of: HS_Study_Object.

Scope note: This class comprises physical portions of matter intended to be representatives for the objects or the environment to be analysed. They usually include pieces of artefacts, portions of inorganic materials, fluids and organic materials e.g., bones, tissues etc. As in the case of the study objects, keeping provenance information is fundamental also for samples. Preserving a persistent link between a sample and the artefact from which it was extracted is equally important.

Examples: -The sample extracted from a bone and chemically treated to be transformed in graphite and dated with radiocarbon method.

-The sample extracted from a vase and treated to extract the luminescent crystals to perform Thermoluminescence dating.

Maps to: HS_Sample is equivalent to S13 Sample class of CRMsci and AO_Object of AO_Cat.

Domain of: was_taken_from.

HS_Study_Object_Area

Subclass of: HS_Place.

Scope note: This class comprises areas of artefacts or other physical objects occupied by the portions of objects investigated by scientific analyses. Areas are actually instances of places located on objects and thus can be identified by relative coordinates.

Examples: The area of the François Vase of the Archaeological Museum of Florence identified by [xxxx] occupied by the physical portion of the vase investigated using XRF.

Maps to: HS_Study Object is a subclass of E53 Place of CIDOC CRM and AO_Object of AO_Cat.

HS_Device

Subclass of: HS_Object.

Superclass of: HS_Device_Component

Scope note: This class comprises digital instruments used to perform analyses and scientific measurements. Being very specific tools, this kind of objects are usually associated with specific types of analyses and involve the use of specific software. One or more devices and software can be used to perform an analysis or a sample preparation activity.

Examples: - The HVEE Tandetron accelerator in the lab of INFN Florence.

- The transportable tomographic system for large objects of INFN Bologna.

Maps to: HS_Device is equivalent to D8 Digital Device of CRMdig.

Domain of: has_maker.

HS_Software

Subclass of: HS_Object.

Scope note: This class comprises programs, digital tools and any other software used to perform analyses and scientific measurements. This kind of digital objects are usually mounted on or connected to the specific devices used for performing the measurement or analysis.

Examples: - The XRF scanning software "XRF CHNet Tool #1" developed by INFN-CHNet researchers.

- The OxCal software used to perform the calibration in radiocarbon dating (https://c14.arch.ox.ac.uk/oxcal.html).

Maps to: HS_Software is equivalent to D14 Software of CRMdig.

HS_Device_Component

Subclass of: HS_Device.

Scope note: This class describes physical components mounted on devices to perform analyses and scientific measurements. One or more components can be used to configure devices while performing specific analyses or sample preparations.

Examples: - The X-ray tube Moxtek TUB00046-MO5 mounted on the INFN-CHNet XRF scanner.

Maps to: HS_Device_Component is subclass of E18 Physical Thing of CIDOC CRM.

HS_Dataset

Subclass of: HS_Object.

Scope note: This class comprises digital objects generated by the analysis process. A dataset usually contains scientific results and/or their interpretation. A single analysis can generate more than one dataset. They can be typically generated automatically by the software running on the devices used for scientific measurements, or manually by scholars, for example as resulting from the specific observations or interpretations made by them on the analytic results. Datasets can be composed of single files, a set of documents or folders, compressed archives and so on. The format and the content of the files included in the datasets can vary significantly according to the analysis/device by which they were generated: e.g. they can contain numerical values resulting from measurements, graphic representations, images, 3D models, textual descriptions.

Examples: - Raw data (numerical files describing XRF maps, tomographic projections, isotopic ratios, etc.).
- Elaborated data (XRF elemental maps, tomographic reconstructions, etc.)
- Reports (describing experimental conditions, results and their interpretation, etc.).

Maps to: HS_Dataset is equivalent to PE18 Dataset class of CRMpe and AO_Data_Resource of AO_Cat.

Domain of: has_format, has_language, created_using_software, used_by_software, used_by_service, is_accessible_at.

HS_Institution

Subclass of: HS_Actor.

Superclass of: HS_Department.

Scope note: This class comprises research institutions directly involved in experimental analyses and in the creation of related documentation and datasets, or other organisations involved in an indirect way with the scientific process, such as, museums, archaeological institutions, private collections, customers and owners of the objects on which the scientific analyses are carried out.

Examples: The Italian National Institute of Nuclear Physics (INFN).

Maps to: HS_Institution is equivalent to E74 Group of CIDOC CRM and AO_Group of AO_Cat.

Domain of: has_department, has_member.

HS_Department

Subclass of: HS_Institution.

Scope note: This class comprises departments, branches, sections or any other specific internal subdivision/organisation of a research institution or other organisation. Since departments receive their identity from institutions as they could not exist without them, the HS_Department class is defined as a subclass of HS_Institution.

Examples: The Florence department of the Italian National Institute of Nuclear Physics (INFN).

Maps to: HS_Department is a subclass of E74 Group of CIDOC CRM and AO_Group of AO_Cat.

HS_Person

Subclass of: HS_Actor.

Scope note: This class comprises people directly or indirectly involved in the various analyses and scientific investigations, such as researchers, analysts, technical operators, but also project managers, responsible, coordinators, people that are personally owners and/or holders of the artefacts, as well as any other people to be mentioned within the metadata.

Examples: Lisa Castelli, a physicist of the Florence department of the Italian National Institute of Nuclear Physics (INFN).

Maps to: HS_Person is equivalent to E21 Person of CIDOC CRM and AO_Person of AO_Cat.

CRMhs Properties

This section presents in detail all the properties of the CRMhs model. A simple notation is used for description. In particular, property axioms are stated using a common template giving:

- the name of the property, given as the title of the section presenting the property; CRMhs properties are named similarly to the way classes are named, except that no prefix is used.
- the domain(s) of the property; following standard semantics, where several domains are given, their intersection is meant.
- the range(s) of the property; following standard semantics, where several ranges are given, their intersection is meant
- the name of the inverse of the property, for properties ranging over classes.
- scope notes stating the informal semantics of the property.
- examples of relationships that are instances of the property.
- the property(ies) or chain of properties the defined property maps to. A chain of property (called "shortcut" in CIDOC CRM) is given as the sequence of the properties, separated by the classes that are the range of the intermediate properties. For example: the CRMhs property has_identifier is a shortcut of the fully developed path E1 CRM Entity → P1 is identified by → E42 Identifier of CIDOC CRM.

has_identifier

Domain: HS_Entity.

Range: xsd:string /rdfs:Resource.

Scope Note: This property is used to assign identifiers of various types (unique, internal, persistent etc.) to instances of the various entities of the model.

Examples: - The https://www.wikidata.org/wiki/Q252376 URI used to identify the François Vase of the Archaeological Museum of Florence (HS_Study_Object) in WikiData.
- The inventory number of an object in a museum.
- The internal identifier assigned by an Institution to a device.
- The identifier assigned by the system to a certain dataset.

Maps to: The has_identifier property is a shortcut of the fully developed path E1 CRM Entity → P1 is identified by → E42 Identifier of CIDOC CRM. It is also equivalent to has_identifier, has_original_id, has_agent_identifier of AO_Cat.

has_type

Domain: HS_Entity.

Range: HS_Type.

Scope Note: This property is used to assign typologies and classify instances of entities of this model according to vocabularies, taxonomies or other specific typologies shared between different institutions or at a global level. Instances of HS_Type, defined as range of this property, can be structured by using the has_uri and the has_label properties to provide specific identifiers and labels for the used concepts.

Examples: - The François Vase of the Archaeological Museum of Florence has_type "volute krater" (http://vocab.getty.edu/page/aat/300198856 in Getty AAT).

- The Radiocarbon analysis performed to date a biological sample coming from an Etruscan tomb has_type http://vocab.getty.edu/page/aat/300054717 ("radiocarbon dating" in Getty AAT).

Maps to: has_type is equivalent to P2 has type of CIDOC CRM. It is also equivalent to has_type, has_native_subject of AO_Cat.

has_name

Domain: HS_Entity.

Range: xsd:string.

Scope Note: This property is used to indicate official, conventional or common names or denominations assigned to instances of the entities of this model.

Examples: -The analysed Botticelli's painting has_name "Primavera".

Maps to: The has_name property is a shortcut of the fully developed path E1 CRM Entity → P1 is identified by → E41 Appellation of CIDOC CRM. It is also equivalent to has_title, has_name, has_place_name of AO_Cat.

has_description

Domain: HS_Entity.

Range: xsd:string.

Scope Note: This property is used to provide free-text descriptions and notes to the instances of the entities of this model.

Maps to: The has_description property is a sub-property of the P3 has note property of CIDOC CRM. It is also equivalent to has_description of AO_Cat.

has_uri

Domain: HS_Entity.

Range: xsd:string.

Scope Note: This property is used to assign Uniform Resource Locator identifiers to instances of all the entities of this model.

Examples: The ARIADNEplus project has_uri https://www.ariadne-infrastructure.eu.

Maps to: The has_name property is a shortcut of the fully developed path E1 CRM Entity → P1 is identified by → E41 Appellation → E55 has type "URI" of CIDOC CRM. It is also equivalent to has_homepage, has_place_IRI of AO_Cat.

has_label

Domain: HS_Entity.
Range: xsd:string.
Scope Note: This property is used to assign human readable labels to instances of all the entities of this model.
Examples: The ARIADNEplus project has_label “ARIADNEplus Project”.
Maps to: The has_label property is a shortcut of the fully developed path E1 CRM Entity → P1 is identified by → E41 Appellation → E55 has type “LABEL” of CIDOC CRM. The property is also equivalent to skos:prefLabel of SKOS schema.

was_performed_on

Domain: HS_Activity.
Range: HS_Object.
Inverse: was_the_subject_of.
Scope Note: This property links an instance of HS_Activity with instances of HS_Object to specify the various operations performed on samples, objects or portions of them e.g. to prepare, analyse, preserve, manipulate, discard them.
Examples: The sample subdivision operation was_performed_on sample #38497-001.
Maps to: The analysed property is a sub-property of the P12 occurred in the presence of CIDOC CRM. It is also equivalent to refers_to, is_about, was_present_at of AO_Cat.

in_the_framework_of

Domain: HS_Activity.
Range: HS_Project.
Inverse: has_in_its_framework.
Scope Note: This property specifies the activities that a project supports as part of its overall program.
Examples: The XRF analysis of the François Vase of the Archaeological Museum of Florence was carried out in_the_framework_of the ARIADNEplus Project.
Maps to: The in_the_framework_of property is a sub-property of the PP43i is project activity supported by of CRMpe.

analysed

Domain: HS_Analysis.
Range: HS_Study_Object.
Inverse: was_analysed_by.
Scope Note: This property links an instance of HS_Analysis with instances of HS_Study_Object to specify the samples, objects or portions of them which a given scientific analysis was performed on.
Examples: The XRF analysis number 19826-001 analysed Botticelli’s “Primavera” painting.
Maps to: The analysed property is a sub--property of the O8 observed of CRMsci.

has_sub_activity

Domain: HS_Activity.
Range: HS_Activity.
Inverse: is_subactivity_of.
Scope Note: This property associates an instance of HS_Activity, considered as a main activity, with one or more other instances of HS_Activity performed as parts, subtasks or ancillary activities with respect to the main one. This property, by linking different activities together, is useful to specify sequences and hierarchies of activities carried out in the same research context.
Examples: The AMS analysis Fi001 has_sub_activity the sample preparation Fi_SP001
Maps to: The has_sub_activity property is a sub-property of the P9 consists of property of CIDOC CRM. It is also equivalent to contains_event of AO_Cat.

was_performed_by

Domain: HS_Activity.
Range: HS_Actor.
Inverse: performed.
Scope Note: This property links an instance of HS_Activity with one or more instances of HS_Actor to specify the people or institutions who performed a given scientific activity.
Examples: The XRF analysis on Botticelli's "Primavera" was_performed_by Lisa Castelli (INFN).
Maps to: The was_performed_by property is a sub-property of the P14 carried out by of CIDOC CRM. It is also equivalent to has_publisher, has_creator, has_owner, has_responsible of AO_Cat.

had_participant

Domain: HS_Activity.
Range: HS_Actor.
Inverse: participated_in.
Scope Note: This property links an instance of HS_Activity with one or more instances of HS_Actor to specify the people or institutions involved in a given scientific activity or project.
Examples: The ARIADNEplus project had_participant INFN.
Maps to: The had_participant property is a sub-property of the P11 had participant of CIDOC CRM.

was_performed_at

Domain: HS_Activity.
Range: HS_Place.
Inverse: hosted_activity.
Scope Note: This property is used to specify places where an analysis, experiment, measurement or any other scientific activity took place.

Examples: - The Radiocarbon analysis for dating a biological sample coming from an ancient Etruscan tomb was_performed_at INFN Florence.
- The XRF analysis for the characterization of the tesserae of the Alexander Mosaic of Pompeii was_performed_at the MANN (Museo Archeologico Nazionale di Napoli).

Maps to: The was_performed_at property is a subproperty of the P7 took place at of CIDOC CRM.

was_performed_during

Domain: HS_Activity.

Range: HS_Period.

Inverse: witnessed_activity.

Scope Note: This property is used to specify periods of time during which an analysis, experiment, measurement or any other scientific activity took place.

Examples: - The Radiocarbon analysis for dating a biological sample coming from an ancient Etruscan tomb was_performed_during "2011".

Maps to: The was_performed_during property is a subproperty of the P4 has_time_span of CIDOC CRM.

has_start_date

Domain: HS_Period.

Range: xsd:dateTime.

Scope Note: This property is used to define start dates for analysis, experiment, measurement or any other scientific activity.

Examples: - The Radiocarbon analysis used to date a biological sample has_start_date 2018-01-16T12:32:00.

Maps to: The has_start_date is a shortcut of the fully developed path E4 Period → P4 has time span → E52 Time Span → P79 beginning is qualified by → E63 String of CIDOC CRM.

has_end_date

Domain: HS_Period.

Range: xsd:dateTime.

Scope Note: This property is used to define end dates for analysis, experiment, measurement or any other scientific activity.

Examples: - The Radiocarbon analysis used to date a biological sample has_end_date 2018-01-17T09:30:00.

Maps to: The has_end_date is a shortcut of the fully developed path E4 Period → P4 has time span → E52 Time Span → P80 end is qualified by of → E62 String of CIDOC CRM.

was_funded_by

Domain: HS_Project.

Range: HS_Actor.

Inverse: funded.

Scope Note: This property specifies the HS_Actor(s) the actors (e.g., a State, the European community, a private consortium etc.) who funded a particular project.

Examples: The ARIADNEplus project was_funded_by the EU Commission.

Maps to: The was_funded_by property is a shortcut of the fully developed path PE35 Project → PP56 was award of → PE42 Funding Activity → PP54 had awardee → E39 Actor.

used_method

Domain: HS_Activity.

Range: xsd:string / rdfs:Resource.

Scope Note: This property is used to specify the methodology applied for performing an analysis or measurement. It is usually used in combination with the has_type property that is instead used to describe the kind of analysis carried out (e.g. “radiocarbon dating”, “x-ray fluorescence” and so on).

Examples: The "Ion beam analysis" used_method Particle Induced X-ray Emission

Maps to: The used_method property is a sub-property of the P33 used specific technique of CIDOC CRM.

used_protocol

Domain: HS_Analysis.

Range: HS_Protocol.

Inverse: protocol_used_for.

Scope Note: This property is used to specify the protocol used for performing an analysis or measurement.

Examples: The Sample Preparation for Thermoluminescence dating of the roman amphora AMPH_LAMB_024 used_protocol “Fine Grain”.

Maps to: The used_protocol property is a sub-property of the P33 used specific technique of CIDOC CRM.

used_device

Domain: HS_Analysis.

Range: HS_Device.

Inverse: device_used_for.

Scope Note: This property is used to specify the devices employed for performing an analysis or measurement. It is usually used in combination with the has_type property that is instead used to describe the kind of analysis carried out (e.g. “radiocarbon dating”, “x-ray fluorescence” and so on).

Examples: - The XRF analysis on the mosaic of Alexander used_device “INFN-CHNet XRF Scanner #1”.

Maps to: The used_device property is a sub-property of the P16 used specific object of CIDOC CRM.

used_component

Domain: HS_Analysis.
Range: HS_Device_Component.
Inverse: component_used_for.
Scope Note: This property specifies a physical component mounted on or used together with the HS_Device to perform a scientific analysis.
Examples: The XRF analysis of the mosaic of Alexander with the INFN-CHNet XRF scanner#1 used_component X-ray tube TUB00046-MO5.
Maps to: The used_component is a subproperty of the P16 used specific object of CIDOC CRM.

used_software

Domain: HS_Analysis.
Range: HS_Software.
Inverse: software_used_for.
Scope Note: This property is used to specify the software used for performing an analysis or measurement.
Examples: - The XRF analysis on the mosaic of Alexander performed with "INFN-CHNet XRF Scanner #1" used_software "XRF CHNet Tool #1".
Maps to: The used_software is a subproperty of the P16 used specific object of CIDOC CRM.

produced_dataset

Domain: HS_Analysis.
Range: HS_Dataset.
Inverse: dataset_produced_by.
Scope Note: This property is used to specify the datasets generated by an analysis, measurement or other scientific activity.
Examples: The XRF analysis on the mosaic of Alexander performed with "INFN-CHNet XRF Scanner #1" produced_dataset "XRF_Scan_001.data".
Maps to: The produced_dataset property is a shortcut of the fully developed path S4 Observation → P9 consists of → D7 Digital Machine Event → L11 had output → PE18 Dataset (CIDOC CRM, CRMsci, CRMdig, CRMpe).

prepared

Domain: HS_Sample_Preparation.
Range: HS_Sample.
Inverse: was_prepared_by.
Scope Note: This property associates an instance of HS_Sample_Preparation with one or more instances of HS_Sample to describe how and how the samples were prepared before being analysed.
Examples: The sample preparation Fi_SP001 performed on biological remains from an etruscan tomb prepared sample Fi2020001 for C14 analysis.

Maps to: The prepared property is a shortcut of the fully developed path E7 Activity → P12 occurred in the presence of → E77 Persistent Item.

has_coordinates

Domain: HS_Place.
Range: xsd:string.
Scope Note: This property is used to specify the coordinates of an instance of HS_Place where instances of HS_Event took place. A place could geometrically be represented by a points, boxes or polygons and its coordinates can thus be expressed by strings following any standard reference system notation, including WGS84, GeoJSON, GML or Well-known text (WKT).
Examples: The François tomb of the Ponte Rotto Necropolis in the Etruscan city of Vulci where the François Vase of the Archaeological Museum of Florence was found, has_coordinates “11.6391,42.4174” (WGS 84) - “POINT (11.6391 42.4174) (WKT)”.
Maps to: The has_coordinates property is a sub-property of the P168 place is defined by of CIDOC CRM.

is_made_of

Domain: HS_Study_Object.
Range: xsd:string / rdf:Resource.
Scope Note: This property specifies the material or substance which an investigated study object (i.e., an instance of HS_Study_Object) is made of.
Examples: The François Vase of the Archaeological Museum of Florence is_made_of pottery.
Maps to: The is_made_of property is a subproperty of the P45 consists of in CIDOC CRM.

was_created_by

Domain: HS_Study_Object.
Range: HS_Actor.
Inverse: created.
Scope Note: This property is used to specify the creator of the object involved in a scientific investigation.
Examples: - The “Venere” painting was_created_by “Sandro Botticelli”.
Maps to: The was_created_by property is a shortcut of the fully developed path E24 Physical Human-Made Thing → P108 was produced by → E12 Production → P14 carried out by → E39 Actor.

has_period

Domain: HS_Study_Object.
Range: HS_Period.
Scope Note: This property is used to assign an object or sample involved in a scientific investigation to a specific period.

Examples: The "Venere" by Sandro Botticelli has_period "Rinascimento (Italy)" (http://n2t.net/ark:/99152/p0qhb66pk6z).

Maps to: The has_period property is a shortcut of the fully developed path E18 Physical Thing → P92 was brought to existence by → E63 Beginning of Existence → P10 falls within → E4 Period.

has_location

Domain: HS_Study_Object.

Range: HS_Place.

Inverse: is_location_of.

Scope Note: This property is used to specify the place (e.g. a museum, collection or an excavation context in case of a monument) where the investigated object is usually located.

Examples: The Botticelli's "Venere" has_location Galleria degli Uffizi, Firenze.

Maps to: The has_location property is a sub-property of P55 has current location of CIDOC CRM.

was_found_at

Domain: HS_Study_Object.

Range: HS_Place.

Inverse: witnessed_discovery_of.

Scope Note: This property is used to specify the place (e.g. a museum, collection or an excavation context in case of a monument) where the investigated object was found (e.g. an archaeological site or context) or originally located.

Examples: The François Vase of the Archaeological Museum of Florence was_found_at the François tomb of the Ponte Rotto Necropolis in the Etruscan city of Vulci.

Maps to: The was_found_at property is a shortcut of the fully developed path E18 Physical Thing → O19 was object found by → S19 Encounter Event → O21 has found at → E53 Place.

was_found_by

Domain: HS_Study_Object.

Range: HS_Actor.

Inverse: has_found.

Scope Note: This property is used to specify the actor (e.g. a museum, institution or people) who found and/or removed the study object from where it was originally located, e.g. an archaeological site or context.

Examples: The François Vase of the Archaeological Museum of Florence was_found_by Alessandro François in Vulci.

Maps to: The was_found_by property is a shortcut of the fully developed path E18 Physical Thing → O19 was object found by → S19 Encounter Event → P14 carried out by → E39 Actor.

is_part_of

Domain: HS_Study_Object.
Range: HS_Study_Object.
Inverse: has_part.
Scope Note: This property specifies a physical object of which the study object is part of, thus it is suitable to describe relationships between components and sub-components and to trace hierarchies of components e.g. from fragments up to their original object.
Examples: Marble fragment 492 is_part_of Forma Urbis Romae.
Maps to: The is_part_of property is a sub-property of the P46 forms part of CIDOC CRM.

belongs_to

Domain: HS_Study_Object.
Range: xsd:string / rdf:Resource.
Scope Note: This property specifies a collection, group of objects or other similar sets which the study object belongs to.
Examples: The Farnese Hercules belongs_to Farnese Collection of the Naples National Archaeological Museum.
Maps to: The belongs_to property is a sub-property of the P46 forms part of CIDOC CRM.

has_owner

Domain: HS_Study_Object.
Range: HS_Actor.
Inverse: owns.
Scope Note: This property specifies the Actor who has the legal ownership of the investigated HS_Study_Object at the time of the scientific analysis.
Examples: The “Primavera” painting by Sandro Botticelli has_owner the Italian State.
Maps to: The has_owner property is a sub-property of the P52 has current owner of CIDOC CRM.

has_area

Domain: HS_Study_Object.
Range: HS_Study_Object_Area.
Inverse: is_area_of.
Scope Note: This property identifies a geometric area identified on a physical object, containing the physical portion of the same object investigated by a scientific analysis.
Examples: The François Vase of the Archaeological Museum of Florence has_area the rectangular area, identified by relative coordinates, containing the physical object portion investigated using XRF.
Maps to: The has_area property is a sub-property of the P59 has section of CIDOC CRM.

occupies

Domain: HS_Study_Object_Portion.
Range: HS_Study_Object_Area.
Inverse: is_occupied_by.
Scope Note: This property is used to associate a physical portion of an object with the corresponding geometric area of the same object within which it is located.
Examples: The physical portion of the François Vase of the Archaeological Museum of Florence, investigated by XRF analysis, occupies the rectangular area on the same object identified by relative coordinates.
Maps to: The occupies property is a sub-property of the P156 occupies of CIDOC CRM.

was_taken_from

Domain: HS_Sample.
Range: HS_Object.
Inverse: from_which_was_taken.
Scope Note: This property is used to specify the object from which the investigated sample was extracted.
Examples: The sample S43 used for a C14 analysis, was_taken_from the wooden beam of the ceiling of Villa Lo Specchio in Florence.
Maps to: The was_taken_from property is a shortcut of the fully developed path S13 Sample → O5 was removed by → S2 Sample Taking → O3 Sampled From→ S10 Material Substantial of CRMsci.

has_maker

Domain: HS_Device.
Range: HS_Actor.
Inverse: is_maker_of.
Scope Note: This property is used to specify the producers or makers of the devices used during scientific measurements and analysis.
Examples: The Tandetron accelerator in the laboratory of INFN-CHNet Florence has_maker HVEE.
Maps to: The has_maker property is equivalent to L33 has maker of CRMdig.

has_residence

Domain: HS_Actor.
Range: HS_Place.
Inverse: is_residence_of.
Scope Note: This property is used to specify where institutions, departments or people are located. Typically, an instance of HS_Place can be used in this context to provide information about cities, states or any other place relevant to identify the related actor.
Examples: The INFN-CHNet Florence Department of INFN has_residence Florence, Italy (Geonames: https://www.geonames.org/3176959/)

Maps to: The has_residence property is a sub-property of the P74 has current or former residence of CIDOC CRM.

has_department

Domain: HS_Institution.
Range: HS_Department.
Inverse: is_department_of.
Scope Note: This property is used to associate departments with the institutions they belong to.
Examples: The INFN institution has_department "INFN-CHNet Florence" department.
Maps to: The has_department property is equivalent to P107 has current or former member of CIDOC CRM.

has_member

Domain: HS_Institution.
Range: HS_Person.
Inverse: is_member_of.
Scope Note: This property is used to associate people (e.g. scientists, scholars or any other person involved in the scientific activities described using this model) with the institutions they belong to.
Examples: "INFN-CHNet Florence" has_member Lisa Castelli.
Maps to: The has_department property is equivalent to P107 has current or former member of CIDOC CRM.

has_email

Domain: HS_Actor.
Range: xsd:string.
Scope Note: This property is used to assign email addresses to instances of HS_Actor, being them institutions or distinct people.
Examples: Lisa Castelli from INFN-CHNet Florence has_email lcas@fi.infn.it.
Maps to: The has_email property is a shortcut of the fully developed path E39 Actor → P1 is identified by → E41 Appellation → E55 has type "email" of CIDOC CRM.

has_format

Domain: HS_Dataset.
Range: xsd:string.
Scope Note: This property is used to specify the MIME Type of a dataset.
Examples: The infn_c14_results.pdf has_format "application/pdf".
Maps to: The has_format property is a sub-property of the P2 has type property of CIDOC CRM.

has_language

Domain: HS_Dataset.
Range: xsd:string / rdf:Resource.
Scope Note: This property is used to specify the language of a dataset content.
Examples: The infn_c14_results.pdf has_language “it”.
Maps to: The has_language property is a shortcut of the fully developed path PE18 Dataset → P165 incorporates → E33 Linguistic Object → P72 has language → E56 Language of CRMpe and CIDOC CRM.

created_using_software

Domain: HS_Dataset.
Range: HS_Software.
Inversion: used_to_create.
Scope Note: This property is used to specify the software that was used to create a dataset.
Examples: The infn_c14_results.pdf created_using_software “Adobe Acrobat”.
Maps to: The created_using_software property is a shortcut of the fully developed path PE18 Dataset → P94i was created by → D10 Software Execution → P16 used specific object → D14 Software of CRMdig, CRMpe and CIDOC CRM.

used_by_software

Domain: HS_Dataset.
Range: HS_Software.
Inverse: used_for_dataset.
Scope Note: This property is used to specify the software or application that is able to open/edit/analyse a dataset.
Examples: The infn_c14_results.pdf used_by_software “Adobe Acrobat Reader”.
Maps to: The used_by_software property is a shortcut of the fully developed path PE18 Dataset → P19i was made for → D10 Software Execution → L23 used software or firmware → D14 Software of CRMdig, CRMpe and CIDOC CRM.

used_by_service

Domain: HS_Dataset.
Range: xsd:string / rdf:Resource.
Scope Note: This property is used to specify an online or local service, web or cloud application that is able to open/edit/analyse a dataset.
Examples: The infn_c14_results.pdf used_by_service “ARIADNEplus NLP Service”.

is_accessible_at

Domain: HS_Dataset.
Range: xsd:string.

Scope Note: This property is used to specify the address of an online or local server, cloud or web service from which the dataset is accessible. A Uniform Resource Locator (URL) can be specified as a value of this property.

Examples: The infn_c14_results.pdf is_accessible_at "https://www.infn.it/datasets/C14/infn_c14_results.pdf".

Maps to: The is_accessible_at property is a shortcut of the fully developed path PE18 Dataset → PP50 is accessible at → PE29 Access Point of CRMpe.